FIFTH ANNUAL REPORT

OF THE

UNITED STATES GEOLOGICAL SURVEY

TO THE

SECRETARY OF THE INTERIOR

1883-'84

BY

J. W. POWELL

DIRECTOR

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GOVERNMENT PRINTING OFFICE
1885

REPORT

OF THE

DIRECTOR

OF THE

UNITED STATES GEOLOGICAL SURVEY.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., August 6, 1884.

Hon. H. M. TELLER,
Secretary of the Interior:

SIR: I have the honor to transmit herewith my report of the operations of the Geological Survey for the fiscal year ending June 30, 1884.

Permit me to express my thanks for the interest you have taken in the work under my charge.

I am, with great respect, your obedient servant,

J. W. Powell

Director.

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FIFTH ANNUAL REPORT

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UNITED STATES GEOLOGICAL SURVEY.

By J. W. POWELL, *Director*.

TOPOGRAPHIC WORK.

The general plan for the topographic work of the Geological Survey was developed somewhat at length in the last Annual Report of the Director. During the past fiscal year it has been continued according to the plans there set forth. The amount of work has been greater in some districts of country, in others less than in the previous year; but taken together the field-work has been materially increased. The districts in which the work has been most expanded are the North Atlantic and the South Atlantic. It has been contracted in the South Pacific and the Great Basin districts. In the North Atlantic District, work has been undertaken for the first time, and in the South Atlantic the Appalachian work has been pushed forward with an enlarged force.

The accompanying map, Plate I, has been prepared to exhibit the progress of the topographic work. It shows: 1st, the areas surveyed by the General Government and the State governments prior to the beginning of the fiscal year upon such scale and in such manner as to afford available data for the Geological Survey; 2d, the areas covered by the Northern Transcontinental Survey, whose results will be accessible to the Geological Survey; 3d, the districts covered during the fiscal year by the geographic department of the Geological Survey.

NORTH ATLANTIC DISTRICT.

The work of preparing a topographic map of New England has been initiated, the first step being to compile and collate the large body of valuable material already in existence. This compilation is not yet complete, but has been carried so far that certain areas can be selected for field-work, and upon one of these a single party, under the direction of Mr. H. F. Walling, has taken the field. In Massachusetts the Commonwealth has undertaken to co-operate with the Geological Survey, and has appropriated for this purpose $40,000, which will be available for three years. The work in that State will therefore be pushed with vigor.

SOUTH ATLANTIC DISTRICT.

In the southern part of the Appalachian region triangulation has been continued by Profs. W. C. Kerr and J. H. Gore, and five topographic parties have been kept in the field during the greater part of the summer and autumn. The areas surveyed were comprised in the western part of Maryland, the northern and southern parts of West Virginia, southwest Virginia, western North Carolina, and eastern Tennessee, and are defined upon the accompanying map. The entire area surveyed was about 19,750 square miles.

As a basis for a local geologic study, by Mr. W J McGee, a detailed, large-scale map of the District of Columbia and adjacent portions of Virginia and Maryland has been commenced. The topography will be exhibited by contours with vertical intervals of 20 feet. A large amount of valuable data already acquired by the Coast and Geodetic Survey and by the United States Engineers has been compiled, and field-work is being prosecuted by Mr. Sumner H. Bodfish.

ROCKY MOUNTAIN DIVISION.

Work in Colorado has been, as heretofore, of a detailed nature, and conducted with special reference to the geologic work of Mr. S. F. Emmons. It has been in the immediate charge of Mr. Anton Karl. The survey of the Elk Mountain

district has been nearly completed, and a map of the neighborhood of Denver has been made on a large scale.

The survey of the Yellowstone National Park has been continued, under the direction of Mr. J. H. Renshawe, and half of the area has been surveyed topographically with sufficient detail for the construction of a map on the scale of one inch to the mile.

The survey of the Southern Plateau region has been continued, under the direction of Prof. A. H. Thompson. One party has devoted itself to triangulation, and three parties have been engaged in topography, covering the total area of 22,000 square miles. In connection with this work a new determination of the astronomic co-ordinates of Fort Wingate has been made.

DISTRICT OF THE GREAT BASIN.

Topographic work in this district has been performed by Mr. Willard D. Johnson, in connection with geologic work by Mr. Israel C. Russell. A detailed map of the hydrographic basin of Mono Lake has been made, for the purpose of exhibiting its remarkable glacic and volcanic features.

DISTRICT OF THE PACIFIC.

Mr. Gilbert Thompson has continued to direct the work of two parties in northern California. Besides carrying forward the general survey of the region on the standard scale, he has begun and nearly completed a detailed map of Mount Shasta and its immediate surroundings. A field-map covering about 24,000 square miles in northern California is now ready for the use of geologists.

The survey of the quicksilver districts of California, by Mr. J. D. Hoffman, has been completed, and detailed maps of the Sulphur Bank, New Almaden, Knoxville, and New Idria districts have been constructed.

GEOLOGIC WORK.

SURVEY OF THE YELLOWSTONE NATIONAL PARK, BY MR. ARNOLD HAGUE.

In the year 1878 the Yellowstone National Park was revisited by the Survey of the Territories under Dr. Hayden, and a painstaking examination of the geysers and hot springs was made by Dr. A. C. Peale. The record of this work has recently been published, and has proved of great value for comparative purposes. During the past year Mr. Hague and his assistants have repeated the greater part of Dr. Peale's temperature measurements, for the purpose of ascertaining what changes have taken place in the interval. Mr. Hague has likewise undertaken a systematic investigation of the physics of geyser action, and has supplemented the field observations by a series of laboratory experiments, which in turn have indicated questions to be determined by still more elaborate observations in the field. He has likewise applied himself to the thorough determination of the geologic structure of the area, and has not neglected the considerations affecting the reservation as a great national park.

The complementary office work has included, besides the experiments on the physics of geyser action, a detailed examination of the incrustations and other deposits from hot springs, and a careful lithologic examination of the rocks. Much time has likewise been devoted to a general study of the volcanic rocks of the Great Basin. This was rendered necessary by the importance of the volcanic problems opened by Mr. Hague's study of the geology of the Eureka Mining District. Finding himself led by the local phenomena to conclusions at variance with the views generally entertained in regard to the igneous rocks of the region, he has been unwilling to permit his memoir to go to press until a general review of the subject had satisfied him as to the validity and bearing of his conclusions.

STUDIES IN DAKOTA AND MONTANA, BY DR. F. V. HAYDEN.

Accompanied by Dr. A. C. Peale, Dr. Hayden has made a series of examinations along the line of the Northern Pacific Railroad and the course of the Yellowstone River from Bismarck, Dak., to Livingston, Montana. The relations of the Laramie formation to the underlying rocks were investigated at numerous points, and important collections were made, especially of fossil plants. The initial steps were also taken for a study of the mineral waters of Montana.

The office work has consisted mainly of the elaboration of the field material, but Dr. Peale has also carried forward the preparation of a bibliography of the thermal springs of the United States, and has begun a subject-index to the publications of the United States Geological Survey of the Territories.

STUDY OF GLACIAL PHENOMENA, BY PROF. T. C. CHAMBERLIN.

The vestiges of ancient ice action, which occupy Mr. Chamberlin's attention, are so widely distributed throughout the northern portion of the United States, and are so diversified in character and arrangement, that their complete elucidation can result only from protracted observation and study. Each year witnesses some important contribution, and under Mr. Chamberlin's administration the problems to be solved and the methods of research are rapidly assuming definite shape. His principal assistants during the year have been Prof. R. D. Salisbury and Prof. J. E. Todd. Prof. Todd in Dakota, and Mr. Chamberlin in Illinois, Indiana, and Ohio, have been engaged in the detailed study of the great moraine and its associated deposits, while Prof. Salisbury has been chiefly occupied with an examination of the driftless area and its borders. In southwest Wisconsin and adjacent portions of Illinois, Iowa, and Minnesota there is a tract which was completely surrounded, but appears never to have been crossed, by the northern ice, and the contrasts afforded by its topography and other surface features afford a valuable basis for the estimation of the amount of degradation accomplished by the ice.

STUDY OF THE ARCHÆAN ROCKS, BY PROF. ROLAND D. IRVING.

The classification of the newer geologic formations is effected by means of their contained fossils. The older formations contain no fossils, and the only characters for their classification are afforded by their structure and lithologic constitution. As a rule, the results attained by the aid of these have been uncertain, and definite conclusions can be reached only at the cost of the most patient and laborious field exploration and lithologic study. East of the Rocky Mountains there are two principal areas occupied by these rocks, the first coinciding roughly with the Appalachian mountain system, the second occupying the northern portions of Michigan, Wisconsin, Minnesota, and Dakota. The latter district is Mr. Irving's field of study. During the past summer and autumn five field parties were engaged for various periods in explorations under his direction, their fields of operations including portions of each of the States mentioned. The office work, which was performed at Madison, Wis., by a small force, consisted largely in the study of the collected rocks by the aid of the microscope. A large number of transparent sections were prepared, and on these were based numerous descriptions, drawings, and photographs to be used in the publication of the results. A special study has likewise been made of the origin of quartzite and of the nature of the process of induration in sand rocks.

STUDY OF THE QUATERNARY LAKES OF THE GREAT BASIN, BY MR. G. K. GILBERT.

The ancient lakes whose vestiges record an epoch of relative humidity in the now barren valleys of the Great Basin, have been a subject of study since the inauguration of the Survey. During the past summer Mr. Israel C. Russell, Mr. Gilbert's principal assistant, has continued and completed the field examinations of the basin of Mono Lake, and of the vestiges of Lake Lahontan, a body of water formed by the expansion and union of Pyramid, Winnemucca, Carson, and Walker lakes, Nevada. Other vestiges of a similar nature are known to exist in the more southerly portions of the Great

Basin, but it has been determined to defer the examination of these for the sake of strengthening the geologic force of the eastern portion of the United States. In connection with the preparation of his material for publication Mr. Gilbert has secured the co-operation of Prof. E. S. Dana and Mr. R. Ellsworth Call, who undertake the discussion of certain special problems, mineralogic and conchologic.

SURVEY OF THE CASCADE RANGE, BY CAPT. C. E. DUTTON.

Captain Dutton's preliminary study of the Hawaiian volcanoes, referred to in my last report, furnished so large a mass of material suitable for immediate publication; that it was thought best to defer his personal field-work in the Cascade Mountains until his Hawaiian papers were completed and published. A reconnoissance was made, however, by Mr. J. S. Diller, who was engaged as Captain Dutton's assistant, and the mapping of the region was continued. Mr. Diller visited Mount Shasta and the southern portion of the Cascade Range, making local observations and collecting material for lithologic study as he went, but giving especial attention to the more general relations of the volcanic and sedimentary masses, so as to enable Captain Dutton to plan future work in the division intelligently. He has since made careful studies of the rocks collected, besides conducting various investigations in microscopic lithology for other divisions of the Survey.

SURVEY OF THE DISTRICT OF COLUMBIA AND ADJACENT TERRITORY, BY MR. W J M'GEE.

There is a zone of country extending from the upper waters of the Hudson River in a direction west of south to the James River, marked by the head of tide-water, where the streams from the mountain regions to the west and north plunge rapidly from their more quiet currents above into tide-water below. This belt of great river declivity extends from the James southwestward to the Savannah at a distance from the border of tide-water. This zone is of great interest by reason of a variety of geologic features therein presented. During the past season, work on this zone has been commenced by Mr. W J

McGee, and he has made a thorough reconnoissance with the District of Columbia as a center, extending therefrom on all sides over an area of several hundred miles. His researches have already thrown much light upon the interesting but obscure problems of the zone above mentioned.

ECONOMIC STUDIES IN COLORADO, BY MR. S. F. EMMONS.

The principal field-work connected with this study has pertained to the Silver Cliff mining district. This is now practically complete, although a short supplementary visit remains to be made. The mining field selected for consideration next in order is that known as the Gunnison region, a large district of scattered mines requiring much topographic work before it can be profitably studied by the mining engineer. The topographic survey being as yet incomplete, Mr. Emmons has turned his attention to problems connected with the water-supply of Denver. The artesian wells of that place depend for their success upon a broad synclinal of the strata; and a detailed study of the basin, by determining the extent of the catchment area and of the porous strata serving as reservoirs, will lead to valuable conclusions in regard to the quantity of the supply and the extent of the artesian district.

Reports on the Ten-Mile district and on the coal-field of Golden are in advanced preparation. Mr. Whitman Cross and Mr. William F. Hillebrand have continued, in the office at Denver, their investigations of the constitution and chemical composition of the ores and other rocks collected in connection with the economic investigations.

SURVEY OF MINING DISTRICTS, BY MR. G. F. BECKER.

Mr. Becker has continued his investigation of the quicksilver mines of California, and has completed his field-work. The districts surveyed this year were the Sulphur Bank, the Knoxville, and the New Idria. To arrive at a full understanding of the geologic relations of the mines it was found necessary to map and study contiguous areas, and incidentally the field-work has afforded a large amount of information in regard to the structure of the Coast Ranges. The chemic problems

developed are numerous and important, and in their study Mr. Becker has been ably seconded by Dr. W. H. Melville.

Mr. J. S. Curtis has completed his examination of the mines of Eureka, Nev., and his report, already in type, will shortly appear.

PALEONTOLOGIC WORK.

WORK OF PROF. O. C. MARSH.

The collecting parties referred to in my last Annual Report have been continued in the field, and their efforts have, as before, been rewarded by the discovery of large quantities of vertebrate remains. While supervising this work of collection, Professor Marsh has given his personal attention chiefly to the study of the material already accumulated and the preparation of monographic reports.

In the systematic treatment of paleontologic material, two general methods of classification have been adopted. The first groups together all the animals entombed at one horizon in the rocks, or, in other words, all those which co-exist on the surface of the earth, and considers them as a fauna. The second groups together those animals most closely allied in structure, and, regarding them as a biologic class, discusses their development, or their progressive change from age to age. The latter method is selected by Professor Marsh, and is appropriate to the magnitude of the collections in his hands. His last memoir described a remarkable order of birds furnished with teeth. One which is now in press describes an order of extinct mammals, the Dinocerata. A third, which approaches completion, treats of the Sauropoda, an extinct reptilian order, several species of which were of gigantic size.

WORK OF DR. C. A. WHITE.

The study of invertebrate fossils of the later geologic ages has been continued by Dr. C. A. White. Last summer was devoted to an investigation of the Laramie beds of Montana and Dakota, the neighborhood of Fort Benton being traversed by land conveyance, and the Missouri River followed for 1,000

miles in a row-boat. During the winter he prepared several paleontologic papers for publication, and is now engaged in the study of collections made by the Division of the Pacific.

Mr. Lawrence C. Johnson continued his work of collection from the Cretaceous and Tertiary rocks of the Gulf States until January, and has since been engaged in labeling and arranging the fossils.

WORK OF MR. CHARLES D. WALCOTT.

The work on the invertebrates of the lower formations has continued under the general charge of Mr. Walcott. He spent a few weeks in a local study of Cambrian rocks exposed along the eastern base of the Adirondack Mountains, but the greater portion of his time has been devoted to paleontologic studies in the office, and especially to the completion of his report on the paleontology of the Eureka district, Nevada, which is now in press.

Prof. Henry S. Williams has been engaged on a comparative study of the Devonian sections of western New York, and other faunas. The work is yet incomplete, but a report of progress has been published as a bulletin of the Survey.

Local work of a more or less independent character has been performed in Wisconsin by Prof. L. C. Wooster, in Alabama by Mr. A. M. Gibson, in Virginia and West Virginia by Mr. H. R. Geiger, and in Tennessee by Prof. Ira Sayles.

WORK OF MR. LESTER F. WARD.

The investigation of fossil plants has this year consisted chiefly of office and laboratory work, but Mr. Ward spent a few weeks in Montana and Dakota collecting from the Fort Union group in the vicinity of Glendive, and also made a voyage down the Missouri River in company with Dr. White.

The use of American fossil plants in the correlation of strata has been greatly restricted by the want of a comprehensive treatise on paleobotany, and because the literature of the subject is widely scattered. As an initiatory step toward remedying this defect and placing the study of fossil plants upon an equal footing with other departments of paleontology, Mr.

Ward has undertaken the preparation of a bibliography of the subject. To this work he has devoted himself with a force of clerks during the greater portion of the year.

WORK OF PROF. WILLIAM M. FONTAINE.

During last summer Professor Fontaine made extensive collections of fossil plants from the newer Mesozoic and Tertiary strata of eastern Virginia, and has been since occupied in determining, describing, and drawing them for publication.

CHEMIC WORK.

WORK OF PROF. F. W. CLARKE.

Previous to the present year the analytic work of the Survey was performed exclusively by chemists attached to its various divisions; but there has been a demand for a general laboratory to which chemic problems could be referred by divisions or members of the organization whose amount of work did not warrant the equipment of a laboratory. This need has now been met by the institution of a laboratory in connection with the central office. Its management has been intrusted to Prof. F. W. Clarke, with Dr. Thomas M. Chatard as assistant. More recently Dr. Frank A. Gooch has been added to the force, the chemic work of the Yellowstone division being assigned to him. Although the laboratory was not fully equipped until December, a large number of analyses have already been reported; and besides the routine work of this nature performed for geologists, two lines of special mineralogic investigation have been instituted by the chemists. The problems they have thus undertaken to solve refer to the origin of certain varieties of rock-structure, and have an ultimate geologic value.

The physical investigations by Dr. Carl Barus have been continued, his attention being still directed chiefly to the means of measuring high temperatures. He has also continued an investigation begun by Prof. W. H. Brewer on the conditions

of subsidence of very fine particles suspended in liquids, a subject of great geologic importance. Dr. William Hallock has remained as his assistant, but was temporarily detailed for duty in the Yellowstone Park, where he studied with Mr. Hague the physics of geyser action.

STATISTICS.

MINERAL PRODUCTION OF THE UNITED STATES, BY MR. ALBERT WILLIAMS, JR.

Mr. Williams's first statistical report, entitled "The Mineral Resources of the United States," carried the figures of production of the several metals and mineral substances to the close of the year 1882. Owing to the fact that no funds were available for the preparation of an annual report for 1883, the statistics for that year will be published, together with those for 1884, in a volume to appear early in the coming spring.

PRELIMINARY GEOLOGIC MAP OF THE UNITED STATES AND THESAURUS OF AMERICAN FORMATIONS.

On August 7, 1882, the operations of the Geological Survey were extended over all the United States by authority of law. On this enlargement of its sphere of activities it seemed wise to colligate the results of all previous geologic surveys and scientific observations relating thereto throughout the United States. For this purpose it was proposed to prepare a preliminary map of the United States, on which should be represented the present status of knowledge relating to areal geology. After such study of the subject as could be given it, the work was placed in the hands of Mr. W J McGee. Subsequently Professor Hitchcock, of Amherst College, who had previously been engaged in similar work, was called to his assistance. The preparation of such a map was found to involve many difficulties by reason of the varying degrees of

exactness with which geologic surveying has been executed in different portions of the country, and through the further fact that large districts in the western portion of the United States have had their areal geology presented on maps purely by hypothesis. The difficulties consisted in eliminating the wholly hypothetic and harmonizing the partially hypothetic with fully-determined facts.

A map of the United States, Plate II, is presented herewith, exhibiting the present state of compilation. It must be understood that this map does not fully represent the present knowledge of the areal geology of the country, but that in some portions, especially in the far west, the compilation is not yet perfected. The map has been colored by groups, as follows:

Quaternary.	Devonian.
Plio-Miocene.	Silurian.
Oligo-Eocene.	Cambrian.
Cretaceous.	Archæan.
Jurasso-Triassic.	Volcanic.
Permo-Carboniferous.	

In connection with the preparation of the map above described, a thesaurus of American geologic formations has been projected and much work done thereon. With this thesaurus a second map, embracing New York, Pennsylvania, and New Jersey, has been projected. The area embraced has long been a field of careful investigation, and is considered to be that portion of the United States the geology of which is best known. The map is to be colored by formations.

The thesaurus and maps above described are designed to serve a secondary purpose. For a number of years a congress of geologists has assembled annually in some European city, having for a part of its functions the preparation of a color-scheme for the representation of areal geology, and a plan of classification and nomenclature for geologic formations, groups, and systems. In this congress American geology and geologists have been but imperfectly represented; and it is proposed in the near future to more thoroughly present the claims of American geology for consideration, especially as that subject

is represented by the Geological Survey of the United States. In this presentation the thesaurus and maps will be of great value.

BIBLIOGRAPHY OF NORTH AMERICAN GEOLOGY.

As another means of marking the point of departure fixed by the enlargement of the duties of the Survey, a scheme for the preparation of a bibliography of North American geology has been under consideration. To this end much work has already been accomplished in the department of paleontology by the several paleontologists of the Survey, and especially by Mr. Ward in paleobotany.

Mr. C. C. Darwin, the Librarian of the Survey, is now engaged in the preparation of a catalogue of publications on North American geology, and the work is well under way. In addition to this, it is proposed to prepare a series of topical bibliographies. Some of these will be made by the geologists of the Survey, each one preparing a bibliography of the subject in which he is specially engaged. But a more comprehensive plan seems desirable, the elaboration of which requires careful consideration. The following scheme of topics has been devised, but is subject to modification as the work progresses:

I. Volcanic Geology, including the phenomena relating to the internal heat of the earth, volcanoes, and the origin and movements of molten matter.

II. Diastrophic Geology, including the phenomena of seismism and the movements of the crust of the earth by faulting, flexure, and implication.

III. Hydric Geology, including the phenomena of degradation and deposition by aqueous agencies.

IV. Glacic Geology, including the phenomena of degradation and deposition by ice.

V. Eolic Geology, including the phenomena due to the agency of winds.

VI. Biotic Geology, including the phenomena resulting from the agency of plants and animals.

VII. Anthropic Geology, including the phenomena resulting from the agency of man.

VIII. Lithic Geology, including the phenomena relating to the chemic and mineral constitution of rocks and their metamorphism.

IX. Petromorphic Geology, including the phenomena relating to the mechanical structure of rocks, as beds, strata, and formations.

X. Geochronic Geology, including the phenomena of the succession and grouping of formations.

XI. Choric Geology, including the phenomena relating to the areal distribution of formations, rocks, and minerals.

XII. Geomorphic Geology, including the phenomena of geodesy and the evolution and classification of topographic features (physical geography).

XIII. Economic Geology, including the phenomena of exploitation, metallurgy, and statistics.

XIV. Geologic Technology, or the art of geologic surveying and publication.

THE PUBLICATIONS OF THE SURVEY.

Under the provisions of the organic law of the Survey the greater part of its publications are held for sale or for exchange for other scientific publications. The Annual Report of the Director is distributed gratuitously, as an executive document, constituting a part of the annual report of the Secretary of the Interior accompanying the President's message to Congress. The distribution of the books, maps, and photographs published by the Survey is made through the Librarian. Of the Annual Reports there have been published:

I. First Annual Report to the Hon. Carl Schurz, by Clarence King. Washington, 1880. 8vo. 79 pages. Large map. A preliminary report describing plan of organization and publications.

II. Report of the Director of the United States Geological Survey for 1880–'81, by J. W. Powell. Washington, 1882. 8vo. lv, 588 pages. 61 plates. Large map.

III. Third Annual Report of the United States Geological

Survey, 1881–'82, by J. W. Powell. Washington, 1883. 8vo. xviii, 564 pages. 67 plates and maps.

IV. Fourth Annual Report of the United States Geological Survey, 1882–'83, by J. W. Powell. Washington, 1884. 8vo. xii, 473 pages. 85 plates and maps.

The Third and Fourth Reports have not yet been received from the Public Printer in bound form for exchange.

The books for sale are classed as Monographs, Bulletins, and Statistic Papers.

The list of the Monographs, so far as already determined upon, is as follows:

I. The Precious Metals, by Clarence King. In preparation.

II. Tertiary History of the Grand Cañon District, with atlas, by Capt. C. E. Dutton. Published.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. Published.

IV. Comstock Mining and Miners, by Eliot Lord. In press.

V. Copper-bearing Rocks of Lake Superior, by Prof. R D. Irving. In press.

VI. Older Mesozoic Flora of Virginia, by Prof. William M. Fontaine. In press.

VII. Silver-lead Deposits of Eureka, Nevada, by Joseph Story Curtis. In press.

VIII. Paleontology of Eureka District, Nevada, by Charles Doolittle Walcott. In press.

Geology and Mining Industry of Leadville, with atlas, by S. F. Emmons. In preparation.

Geology of the Eureka Mining District, Nevada, with atlas, by Arnold Hague, In preparation.

Lake Bonneville, by G. K. Gilbert. In preparation.

Dinocerata: A monograph on an extinct order of Ungulates, by Prof. O. C. Marsh. In press.

Sauropoda, by Prof. O. C. Marsh. In preparation.

Stegosauria, by Prof. O. C. Marsh. In preparation.

Of these Monographs, Nos. II and III only have been published, viz:

II. Tertiary History of the Grand Cañon District, with atlas, by C. E. Dutton, captain of Ordnance, U. S. A. 1882.

4to. 264 pages. 42 plates and atlas of 26 double sheets folio. Price, $10.12.

III. Geology of the Comstock Lode and Washoe District, with atlas, by George F. Becker. 1882. 4to. 422 pages. 7 plates and atlas of 11 sheets folio. Price, $11.

Nos. IV, V, VI, VII, and VIII are in press, and will appear in quick succession. The others, to which numbers are not assigned, are in preparation.

The Bulletins of the Survey will contain such papers relating to the general purpose of its work as do not come properly under the heads of Annual Reports or Monographs.

Each of these Bulletins will contain but one paper, and will be complete in itself. They will be numbered in a continuous series, and in time will be united into volumes of convenient size. To facilitate this, each Bulletin will have two paginations, one proper to itself, and another which belongs to it as part of the volume.

Of this series of Bulletins, Nos. 1, 2, and 3 are already published, viz:

1. On Hypersthene-Andesite and on Triclinic Pyroxene in Augitic Rocks, by Whitman Cross, with a Geological sketch of Buffalo Peaks, Colorado, by S. F. Emmons. 1883. 8vo. 40 pages. 2 plates. Price, 10 cents

2. Gold and Silver Conversion Tables, giving the coining value of Troy ounces of fine metal, &c., by Albert Williams, jr. 1883. 8vo. 8 pages. Price, 5 cents.

3. On the Fossil Faunas of the Upper Devonian along the meridian of 76° 30′, from Tompkins County, New York, to Bradford County, Pennsylvania, by Henry S. Williams. 1884. 8vo. 36 pages. Price, 5 cents.

The fourth series of publications has special reference to the mineral resources of the United States. The first volume has been published, viz:

Mineral Resources of the United States, by Albert Williams, jr. 1883. 8vo. xvii+813 pages. Price, 50 cents.

SALE OF PUBLICATIONS.

The demand by purchasers for the publications of the Survey has not been large, and in but one instance—that of the

"Mineral Resources"—has it threatened to encroach upon the number needed for exchange. All who wished to purchase have been supplied, and yet no efforts have been made to secure purchasers. The interests of the Survey are naturally against a sale which brings to it no advantage, and the proceeds of which are covered into the general fund of the Treasury of the United States, and in favor of an exchange which adds books and maps to its library. Below is a tabulated statement of sales during the fiscal year of 1883–'84.

Title of work.	First quarter.		Second quarter.		Third quarter.		Fourth quarter.		Whole year.	
	Volume.	Amount.	Volume.	Amount.	Volume.	Amount.	Volume.	Amount.	Volume.	Amount.
Monograph II	6	$60 72	8	$80 96	2	$20 24	4	$40 48	20	$202 40
Monograph III			4	44 00	6	66 00	3	33 00	13	143 00
Bulletin 1	1	10	6	60	5	50	1	10	13	1 30
Bulletin 2			22	1 10	4	20	4	20	30	1 50
Mineral Resources			241	120 50	219	109 50	67	33 50	527	263 50

Whole number of volumes sold, 603. Whole amount received for publications, $611.70.

EXCHANGE OF PUBLICATIONS.

A system of exchange has been inaugurated by means of which the publications of the Survey are distributed to 1,500 scientific institutions and individuals. The Monographs, Bulletins, and Reports of the Survey are sent to 693 of these 1,500. The remaining 807 addresses receive the Annual Report of the Geological Survey in exchange for their publications.

Of these same publications the First Annual Report was distributed under my predecessor, Mr. Clarence King. During the fiscal year 1883–'84 the Second Annual Report has been distributed throughout the world to the whole exchange list. Monograph II and Bulletin 1 have been sent to all on the list for complete exchange, making 3,579 volumes, to which should be added 1,305 volumes of the Twelfth Annual Report of the Survey under Dr. F. V. Hayden, in three volumes, which were sent to the 435 foreign addresses, making in all 4,884 volumes distributed by exchange.

LIBRARY.

The collection of a library was begun in February, 1882. At that time about 400 volumes were on the shelves. The first material increase it received was from Dr. F. V. Hayden, consisting of about a thousand volumes of scientific serials, collected by him as the Superintendent of the United States Geological Survey of the Territories. Soon after this, the library of Mr. Robert Clarke, of Cincinnati, was purchased. For forty years previous to this time Mr. Clarke had been collecting a geologic library. Brought together by a man so competent, and begun so early, it possessed very many of the older and rarer geologic reports, which would have been excessively expensive if collected severally here and there by purchase. The fact that the library was to be public and permanent induced Mr. Clarke to yield this collection in its entirety, and 1,894 volumes thus became the property of the Survey in October, 1882. From this beginning the library has rapidly increased, chiefly by means of exchange, but to a limited extent by purchase.

Contents of library June 30, 1884.

BOOKS.		
Received by exchange (including those received as exchanges by Dr. Hayden, and transferred to the Survey)	8,714	
Received by purchase	2,801	
		11,515
PAMPHLETS.		
Received by exchange	6,400	
Received by purchase	500	
		6,900
Whole number of books and pamphlets		18,415

PHOTOGRAPHIC WORK.

Photography is used by the Survey for a variety of purposes. Many negatives are taken by working geologists in the field for the purpose of illustrating geologic phenomena A photographic laboratory has been organized, under the charge

of Mr. J. K. Hillers, in which photography is used as an aid in changing the scale of charts and preparing various illustrations for the reports. During the year 536 negatives, 6,231 prints, and 94 transparencies have been made in the laboratory.

FINANCIAL STATEMENT.

Amount appropriated by Congress for work of the United States Geological Survey for the fiscal year ending June 30, 1884—

Salaries, office of the Director	$34,940 00	
General expenses	304,700 00	
		$339,640 00
Expended during fiscal year		329,795 63
Remaining on hand July 1, 1884, to meet outstanding liabilities		9,844 37

The following is a classification of the expenditures:

A.—Services	$226,926 18
B.—Traveling expenses	20,307 43
C.—Transportation of property	6,065 60
D.—Field subsistence	11,231 93
E.—Field supplies and expenses	15,014 12
F.—Field material	13,724 35
G.—Instruments	9,308 39
H.—Laboratory material	6,142 43
I.—Photographic material	4,328 55
K.—Books and maps	4,740 26
L.—Stationery and drawing material	2,450 75
M.—Illustrations for reports	979 02
N.—Office rents	942 12
O.—Office furniture	4,495 13
P.—Office supplies and repairs	2,213 99
Q.—Storage	453 41
R.—Correspondence	471 97
	329,795 63

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

ADMINISTRATIVE REPORTS

OF

CHIEFS OF DIVISIONS

AND

HEADS OF INDEPENDENT PARTIES,

ACCOMPANYING THE ANNUAL REPORT OF THE

DIRECTOR OF THE U. S. GEOLOGICAL SURVEY

FOR THE

FISCAL YEAR ENDED JUNE 30, 1884.

REPORT OF MR. HENRY GANNETT.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF GEOGRAPHY,
Washington, D. C., July 1, 1884.

SIR: I have the honor to submit the following report of work performed by your direction and under my charge during the fiscal year ended June 30, 1884.

GENERAL ORGANIZATION OF THE DIVISION

During the field season, work was actively prosecuted in the fields occupied during the previous season, in northern California, in Arizona and New Mexico, in Montana, and in the region of the southern Appalachians. In all these districts, excepting that of Montana, field-work was done in a sufficient degree of detail to admit of publication upon a scale of $\frac{1}{250000}$, or about 4 miles to an inch, and in contours 200 feet apart vertically. In addition to this, which may be classed as general work, a survey of the Yellowstone Park, in sufficient detail to admit of publication upon a scale of $\frac{1}{62500}$, or about 1 mile to an inch, was commenced; the survey of the state of Massachusetts for publication upon a scale of $\frac{1}{125000}$ was begun; and in Colorado a detailed map of the Denver district, upon a scale of 1 mile to an inch, was completed. Besides this work a survey was made of an area in the western part of the Elk Mountains for publication on a scale of $\frac{1}{62500}$.

The work of mapping the quicksilver districts in the Coast range of California was carried forward and was completed in the spring.

NEW ENGLAND DIVISION.

It was decided to commence a topographic map of New England to be published upon a scale of $\frac{1}{125000}$. In accordance with this decision, Prof. H. F. Walling was appointed on the 1st of July for the purpose of taking charge of this work, and field-work was shortly after instituted under his direction in western Massachusetts. A comparison of the triangulation of the Borden survey, made between 1830 and 1842, with that of the United States Coast and Geodetic Survey in this State (many points having been occupied in common), developed the fact that the

former was sufficiently accurate for all the requirements of such work as was projected by the Survey, a slight readjustment only being necessary to fit it to the work of the Coast and Geodetic Survey. The United States Geological Survey was thereby relieved of the necessity of carrying on triangulation, and the expense of the work was consequently greatly reduced. Furthermore, it was believed that the traverse work which had been done in the State, mainly under the direction of Professor Walling, would relieve this organization of the necessity of surveying much of the level country, leaving as the principal work to be accomplished the proper connection of the old traverse work with the geodetic points, the filling in of the drainage in the hills, and the addition of the element of relief throughout the country. Professor Walling's intimate acquaintance with the work which had previously been done in the state rendered him particularly well fitted for the difficult task of handling this material.

Field-work was commenced in the northwestern part of Berkshire county, and extended southward during the season over nearly the whole of the county, together with adjacent strips of New York and Connecticut, which were included for the purpose of filling out atlas sheets. Associated with Professor Walling as assistants in this work were Messrs. R. D. Shepard, S. R. Duval, H. S. Selden, and, as principal assistant during the early part of the season, Mr. W. T. Griswold. During the winter Professor Walling has been employed in computing and platting the season's work, part of the time in Washington, and the remainder in Cambridge, Mass.

THE APPALACHIAN DIVISION.

Work in this division was commenced in June, when one party for carrying on triangulation and three parties for topographic work were put into the field. Early in July a second triangulation party and two topographic parties were added to this division, besides additional details to the parties already in the field.

Triangulation party No. 1 was composed of Prof. W. C. Kerr, in charge, with Mr. S. S. Gannett as assistant. To this party was intrusted the work of extending the triangulation southward and westward from the work of the preceding year, over the mountains of North Carolina and the valley of East Tennessee to the escarpment of the Cumberland plateau. The work was based upon the series of quadrilaterals of the United States Coast and Geodetic Survey along the Blue Ridge, connection being made with the following stations of that organization: Benn, Poore, Hogback, Pinnacle, and Rabun. The work was carried on with a 6-inch theodolite, reading by verniers to 10 seconds. Artificial signals, consisting of trees or tripods of timber, were used in all cases. In spite of the unfavorable atmospheric conditions so prevalent in this mountain region, the season's work was very successful. In all, includ-

ing reoccupation of stations of the preceding year, 25 stations were occupied, by means of which 9,000 miles of topography were controlled. At the end of September Professor Kerr, who had long been suffering from ill health, found it necessary to discontinue field-work, and bring his connection with the Survey to a close. The work was carried on from that time to the end of the season by his former assistant, Mr. S. S. Gannett.

Topographic party No. 1 was, as during the preceding season, in charge of Mr. C. M. Yeates, with Mr. A. F. Dunnington as assistant, and, later in the season, with Mr. F. M. Boteler as aid. The area assigned to Mr. Yeates was comprised in the mountain region of North Carolina, limited laterally by the Blue Ridge and the Smoky Mountains, and extended southwestward from his work of the preceding year. The party commenced work early in June and carried on its operations continuously, excepting when interrupted by bad weather, until the end of November. The area surveyed was 3,250 square miles, including the counties of Madison, Haywood, Henderson, Transylvania, and Wayne, and two-thirds each of Jackson and Buncombe, which comprise a large part of the most rugged and intricate mountain region of the State. The methods of work pursued by Mr. Yeates were similar to those of last year, consisting essentially in making sketches, with locations, from elevated points; a method practically identical with that of the plane-table, excepting that the sketches were corrected in the office instead of upon the ground. The difficulties introduced by the fact that nearly all summits are covered with forests, and that the locations of stations cannot in any case be foreseen, render it, in my opinion, more than questionable whether it would be advantageous to attempt the use of the plane-table. On the other hand, the conformation of the country is so bold as to relieve one of the necessity for doing any traverse work or work of a kindred nature.

Party No. 2 was in charge of Mr. Morris Bien, with Mr. R. C. McKinney as assistant, and, after the 1st of July, Mr. R. M. Towson as aid. To Mr. Bien was assigned that portion of the mountain region of North Carolina lying north of the northern boundary of his work of the preceding season, with the northeastern corner of Tennessee and the southwestern portion of Virginia. This party was very successful, completing not only the portions of North Carolina and Tennessee assigned to it, comprising in the former State the counties of Ashe and Alleghany, and in the latter the county of Carter, with half of Unicoi and Sullivan counties, but also, in Virginia, the counties of Grayson, Russell, Tazewell, Wise, Buchanan, the western third of Washington, and those parts of Scott and Lee which were not surveyed during the previous season; in all an area of, approximately, 5,000 square miles. This district varies greatly in its topography in different parts. The North Carolina and Tennessee areas are mountainous, with several valleys of considerable

breadth, while the Virginia portion of the area is in part made up of the Tennessee valley, consisting of broad valleys intersected by narrow ridges, and in part of the Cumberland plateau, which has here been cut into shreds by erosion, causing the country to consist of a succession of sharp, narrow, tortuous ridges separated by equally narrow and tortuous valleys, without order or system. For each of these kinds of country it became necessary to use different topographic methods.

Topographic party No. 3 was placed in charge of Mr. Frank M. Pearson, with Messrs. S. A. Aplin and H. B. Blair as assistants, and Theodore Tallmadge as aid. To this party, which took the field early in June, was assigned for survey the northern part of the valley of East Tennessee, having as its northern limit the state line, while its lateral boundaries were the escarpment of the Cumberland plateau on the northwest, and the Smoky mountains upon the southeast. During the season, which was a very successful one, an area of 4,750 square miles was surveyed, comprising the counties of Hawkins, Hamblen, Hancock, Knox, Granger, Anderson, Claiborne, half of Campbell, Roane and Loudon, two-thirds of Greene and three fourths of Jefferson County. This area consists of broad valleys separated by long, parallel ridges, some simple and sharp, others broad and flat; while the whole country, except where cultivated, is covered with forests. Under such conditions it was impossible to use the plane-table or methods resembling it, to any great extent. It became necessary to revert to traverse methods in the main, supplemented by sketches and corrected by frequent locations based on triangulation.

Triangulation party No. 2, consisting of Prof. J. Howard Gore, in charge, with Messrs. G. F. Wakefield and S. J. Wilson as assistants, was put into the field early in July, outfitting at Charleston, W. Va. Its instructions were to connect upon the points in the transcontinental work of the U. S. Coast and Geodetic Survey in West Virginia, carry a series of figures southward, and connect upon the south with the work of party No. 1, near the south boundary of Virginia. The selection of stations and the erection of signals occupied the time of this party until early in September, when Professor Gore was obliged to leave the field to resume his college duties. The angular measurement was undertaken and carried on by Mr. Wakefield, with the assistance of Mr. S. J. Wilson. This work was greatly delayed by the storms of autumn, and, as it was absolutely necessary that connection should be carried through as originally projected, the party was kept in the field until January. The instrument used was a 6-inch theodolite reading to 10 seconds.

Early in July a fourth topographic party was organized at Charleston, W. Va., consisting of Mr. W. A. Shumway, topographer, in charge, with Messrs. W. G. Newman and R. H. Chapman as assistants, and T. W. Birney as aid. To this party was assigned that portion of West Vir-

ginia lying between the Big Sandy river on the west and the Kanawha river and the New river upon the east, with the line of the Chesapeake and Ohio railroad for the northern and the state line as the southern boundary. This area, which is entirely hilly or mountainous, consists in general terms of a plateau, sloping northwestward, which has been subjected to great erosion, producing an alternation of sharp ridges and narrow valleys in endless succession, without character or system, excepting the general northwest slope. All the ridges rise, approximately, to the same height, which is, apparently, the original level of the plateau. The whole area is made up of an infinite amount of topographic detail. There are almost no commanding points from which views of large areas can be obtained. Add to this the fact that the whole country is covered with dense forests, and the problem of making even a tolerably correct map except at great expense of time and money becomes a very difficult one. Fortunately, however, fragmentary surveys, for public or private purposes, are so abundant in this region as to cover very nearly its whole area, so that the work was narrowed down to that required for the connection and correction of these fragmentary surveys and the obtaining of the necessary data and knowledge of the country for drawing the hill work in approximate contours. In this work Mr. Shumway was very successful, covering 5,250 square miles during the season.

Early in the same month a fifth topographic party was put into the field, outfitting at Cumberland, Md. The area assigned to it comprised the western part of Maryland, with such adjacent portions of West Virginia lying to the westward and southward as could be included in the work of the season. The topographic work was controlled by triangulation carried on by this party, based upon the stations established by Prof. H. F. Walling, while connected with the United States Coast and Geodetic Survey. From the character of the country, topographic work was necessarily done mainly from traverse lines, no other method being practicable. This party was in charge of Mr. S. H. Bodfish, and comprised, besides himself, Messrs. L. C. Fletcher, Merrille Hackett, and John S. Happer. The area assigned to this party is in the main a plateau considerably elevated above sea-level, surmounted by parallel ranges and ridges of no great elevation. Within the state of Maryland this country is fairly well settled, and there is no special difficulty in the work arising from the presence of forests. To the southward, however, in West Virginia, the forests become very much denser, and they offered a very serious obstacle to the progress of the work. Comparatively little assistance was afforded in West Virginia by the maps of old surveys, while, on the other hand, in Maryland maps are excellent, and cover a large part of the area.

In the latter part of August Mr. Bodfish's health failed, and he was obliged to give up field-work, when Mr. W. T. Griswold, who had for-

merly been connected with the Massachusetts work in charge of Prof. H. F. Walling, was ordered to take charge of this party. Under his direction work was carried on during the balance of the season. Owing in part to the difficult nature of the country in West Virginia, in part to the delays incident to the change in the organization of the party, and, further, to the fact that both triangulation and topography were carried on by this party, the area covered is not as great as that of the other parties, amounting to only 1,500 square miles.

The measurements of altitudes by these parties have been done by the use of the barometer combined with the vertical circle of the gradienter. Base barometric stations were supplied in part by the co-operation of the United States Signal Office, which furnished the Survey with copies of the barometric records at Knoxville and at Chattanooga, Tennessee. At other points temporary stations were established by the Survey, as at Bristol, Tenn., Charleston, W. Va., Oakland, Md., Asheville, N. C., and upon the summit of Mount Pisgah, 17 miles south of Asheville.

The area surveyed by the Appalachian Division during the season aggregates 19,750 square miles. During the winter the triangulation of this party has been adjusted by least squares and reduced; while the topographers have been employed in reducing and platting their field-notes.

DETAILED WORK IN MARYLAND AND THE DISTRICT OF COLUMBIA.

In conformity with your orders, measures were taken in January for the preparation of a map of the District of Columbia and the country adjacent to it, with a view of having a basis for a detailed study of the geology of the region, and particularly of its terrace phenomena. This work, which includes, besides considerable field-work, the compilation of all existing data relating to the region in question, was placed in charge of Mr. Sumner H. Bodfish. The material for a large part of this map was found to be already in existence. The map of the District of Columbia, upon a sufficiently large scale, in contours 20 feet apart, had just been completed by the District authorities, and was available. In addition to this, the United States Coast and Geodetic Survey kindly furnished a chart of the river and manuscript sheets covering a strip of country 3 miles in breadth all around the District and extending up the river on the Maryland side to Great Falls, besides a considerable area in Alexandria County, Virginia. As field-work in this area is necessarily very slow and expensive, these maps were of great assistance. The compilation of this material was completed early in the spring, when Mr. Bodfish took the field, with Mr. C. C. Bassett, who had been ordered east from California, as assistant, and the work has been going on to good advantage. The scale of the plane-table sheets is two inches to a mile, or, approximately, 1:30,000, in contours 20 feet apart vertically.

COLORADO.

During the past year Mr. Karl has been continued upon the detailed work in Colorado, in connection with the geological work of Mr. S. F. Emmons. It was desired to have the map of the Elk Mountain district, which was made in 1874, by the United States Geological Survey of the Territories, extended to the southwestward to include the recent mineral discoveries upon Slate river and its branches and upon Anthracite creek and Coal creek. Mr. Karl proceeded to the field early in July, and immediately commenced work in this region. The country consists in the main of isolated groups of high mountains separated by narrow valleys, a species of country favorable in the extreme for work with the plane-table, which instrument was used to the practical exclusion of all others. Elevations were obtained by means of the vertical circle, checked at intervals by level lines run from the railroad at convenient points. The plane-table sheets were made on a scale of two inches to a mile or about 1:30,000, work being based upon the triangulation of the United States Geological Survey of the Territories. Late in September, when the work was nearly completed, Mr. Karl was suddenly called from it by the Secretary of the Interior, for the purpose of assisting in the survey of the Maxwell grant in northern New Mexico. This work was performed to the entire satisfaction of the Department, and upon its completion, the season being very far advanced, it was judged to be impracticable to carry on any further field-work in the Elk mountains, and Mr. Karl was directed to return to the east. During the winter he has been occupied mainly in platting his map of the Elk mountains. Early in May he was ordered to the field again, for the purpose of completing the Denver map, as it is called. This comprises an area of, approximately, 1,000 square miles, about Denver as a center. Material for this, consisting of the land-survey plats and the maps of the different railroad and ditch companies traversing the area, had been in process of compilation for a year or more. The field-work required to complete the map consisted in the extension of triangulation for its control, and in the sketching and measurement of the relief of the country. This map has now been completed, and Mr. Karl is awaiting further orders.

MONTANA DIVISION.

Among the plans for topographic work for this year was that of a survey of the Yellowstone National Park, in sufficient detail for publication upon a scale of $\frac{1}{62500}$, in contours, approximately, 50 feet apart vertically. Mr. J. H. Renshawe, who was in charge of the Montana Division during the preceding season, was assigned to the immediate direction of this work. He proceeded to Bozeman, Montana, early in July. The following men were assigned to duty with him upon this work: Eugene Ricksecker and Paul Holman, assistant topographers, H. L. Dawes, topographic assistant, W. S. Renshawe and J. D. Colt,

aids, together with Ensigns H. S. Chase and Le Roy M. Garrett, who were detailed from the U. S. Navy for service upon the Survey. The usual delays incident to outfitting postponed the commencement of the work, and it was not until August 6 that the survey actually commenced. The plans of the work required that it should be done, as far as practicable, with the plane-table, supplemented by traverse work upon the forest-covered plateaus, where it is impracticable to use the instrument. Work was commenced in the northwestern portion of the Park, and a very careful survey was made of the southern end of the range, lying about the heads of the West Gallatin river. After finishing in the high mountains the work went forward much more rapidly upon the rolling plateaus to the southward and eastward, and when the party was finally driven out of the Park by the severe weather of the autumn, about 1,000 square miles had been surveyed, extendng southward to the Lower Geyser Basin, and from the west boundary eastward so as to include nearly all of the drainage basin of Gardiner's river and the Gibbon fork of the Madison. The party returned to Bozeman about the middle of October, and preparations were immediately made for remeasuring the base line in the neighborhood of that town, which had been laid out and measured in 1877 by Lieutenant Tillman, under the United States Geographical Surveys west of the 100th meridian. The measurement was made with the secondary base bars belonging to the Survey, and the details of the work were carried out by Ensign Chase. The whole line was divided into three sections, each of which was measured once. The middle section was then remeasured and the lengths of the other two sections were redetermined from it by triangulation, using the middle section as a base. The results of the measurements are as follows:

	Meters.
First measurement of middle section	1,959.916
Second measurement of middle section	1,959.922
Mean measurement of middle section	1,959.919
Measurement of first section	2,875.753
Mean measurement of middle section	1,959.919
Measurement of third section	2,516.969
Total measurement of base	7,352.642
Length by angles	7,352.572
Measured length with weight 10	7,352.642
True length of base	7,352.635

THE WINGATE DIVISION.

This division has remained during the year under the charge of Prof. A. H. Thompson. Early in May, 1883, preparations were commenced

for placing the parties in the field, headquarters being, as during the year before, at Fort Wingate, New Mexico. Three parties were organized, two for topographic work, under charge, respectively, of Messrs. E. M. Douglas and H. M. Wilson, and one for triangulation, under the immediate charge of Professor Thompson. Mr. A. P. Davis, Ensign C. C. Marsh, and Mr. John D. Atkins acted as assistants, respectively, in these parties. A base barometric station was established at the rendezvous camp at Fort Wingate, N. M., with Mr. S. A. Garlick as observer. The parties as thus organized commenced work and continued until July 15, at which time Messrs. W. M. Reed and Edmund Shaw joined the division as topographic assistants, when a reorganization of the division was effected. Mr. Reed was assigned to Mr. Douglas's party, as assistant, in place of Mr. Davis, and Mr. Shaw to Mr. Wilson's party in place of Mr. Marsh. Mr. Davis was given charge of a third topographic party, with Mr. Emanuel Schmelzkopf as assistant. Ensign Marsh was assigned as assistant in the triangulation party in place of Mr. Atkins, who had been ordered to report to the Director at Washington. The parties were furnished with the usual complement of men and animals, and, in addition, were authorized to employ Indians as guides, whenever possible, as it was believed that the cost of their services would be more than repaid by the increased facility thereby gained in traversing the country. The permanent camp and base barometric station were moved to Fort Defiance, Arizona, that point being more central and accessible to the work thereafter than Fort Wingate. Mr. Garlick remained in charge of the base barometric observations. This organization was continued until the close of the field season with but one change, that change being the detachment of Mr. Shaw from Mr. Wilson's party and his assignment as base barometric observer at the rendezvous camp, thus relieving Mr. Garlick, who was given charge of a small party and directed to meander, by courses and distances, all of the wagon roads in the area surveyed by the topographic parties.

To the party under Mr. Douglas was assigned, in the early part of the season, the completion of field-work in the southern part of atlas sheet 35°–108° and, later in the season, the survey of atlas sheets 35°–109° and 35°–110°. The party under Mr. Wilson completed the work in the northern part of atlas sheet 35°–108° early in the season, and later the whole of atlas sheets 36°–109° and 36°–110°, besides small outlying areas. To the party under Mr. Davis was assigned the completion of field-work in atlas sheets 37°–109° and 37°–110°, which comprise the country lying mainly north of the San Juan, east of the Colorado, and west of longitude 109° 30′. On account, however, of threatened difficulties with Navajoe Indians, who range in that region, it was thought best, after Mr. Davis had reached his field of labor, to recall him and assign to him in place of this area, atlas sheet 35°–107°, where he commenced work about September 10.

Mr. Douglas finished work and reached the rendezvous camp at Fort Defiance about November 1. The party was disbanded, Mr. Reed returning to Washington. Mr. Shaw was relieved from duty as barometric observer and ordered to report to the Director at Washington. Mr. Wilson arrived at Fort Defiance soon after Mr. Douglas, having completed the area assigned to him. This party was also disbanded, but Mr. Wilson was retained until December 1, in order to assist in the primary triangulation, at which date he left the field in company with Ensign Marsh and returned to Washington. Mr. Davis was later in closing field-work, owing to the late date at which work was commenced. It was not until November 21 that the area assigned to him was completed. This party was disbanded, but Mr. Davis was retained at Fort Wingate to assist in the determination of the astronomical co-ordinates of that point.

In the early part of the season the triangulation party was engaged in extending the work over the area included in atlas sheets 35°–107° and 35°–108°. This was finished July 1, but, owing to the press of administrative duties, Professor Thompson was unable to take the field with his party again until the middle of August. A further delay occurred owing to the difficulties which had arisen among the Navajoe Indians. It was not until September 15 that the parties were able to proceed in earnest. From this time until December 1, work was prosecuted continuously by Professor Thompson and by Messrs. Marsh, Wilson, and Davis.

The party under Mr. Garlick, detailed for the purpose of traversing the roads, was continuously employed in that work from September 15 to November 20, covering some 700 square miles of route.

During the season the following areas were covered: by Mr. Douglas's party, 8,800 square miles; by Mr. Wilson's, 10,400, and by Mr. Davis's, 3,800; total, 22,000.

Professor Thompson had been instructed, upon the close of field-work, to remain at Fort Wingate and determine its astronomical co-ordinates, connecting for longitude with the Washington Observatory at Saint Louis, Mo., whose director, Prof. H. S. Pritchett, kindly extended every facility for the work. Professor Thompson was assisted in this work by Mr. A. P. Davis. It was effected during the month of December, telegraphic signals being exchanged upon five nights, with the requisite observations for time. Latitude was determined by zenith distances from observations upon 87 pairs of stars, obtained during twelve nights. Upon the completion of this work, Professor Thompson and Mr. Davis returned to Washington.

Office work was commenced by Messrs. Douglas and Wilson in December and by Mr. Davis in January. The reductions of the observations for latitude and longitude have been made by Mr. S. S. Gannett, with satisfactory results.

THE CALIFORNIA DIVISION.

Mr. Gilbert Thompson has remained in charge of this division during the past year. The work projected was in continuation of that commenced during the preceding season, namely, the survey of that portion of northern California comprised in the Coast ranges and the Shasta mountain group. Mr. Thompson left Washington on the 2d of July, taking with him Mr. Mark B. Kerr as topographer, and Mr. Albert Noerr as assistant topographer. Messrs. R. T. Varnum, William B. Hester, Benjamin L. Fairchild, and Robert T. Cummins were also employed as aids and barometric observers. Red Bluff, Cal., was selected as the outfitting point. Two parties were organized, one in charge of Mr. Thompson himself and the other under Mr. Kerr. A barometric base station was established at Berryvale, at an altitude of 3,474 feet, and connected by a line of levels with the location line of the Oregon division of the Central Pacific railroad. A division of the territory proposed for survey was made by giving to Mr. Kerr's party the country lying to the west of the Oregon and California Stage Road, that to the east of that road being selected by Mr. Thompson. The former party, although troubled to some extent by smoke, haze, and bad weather, succeeded very well in its work, covering some 3,000 square miles, nearly all of which consisted of the rugged mountains of the Coast range. Considerable difficulty was experienced from forests, which reached to the crests of the highest mountains.

The party under Mr. Thompson, however, was not as successful. Smoke, haze, and, in the latter part of the season, stormy weather hindered the work. Realizing at the outset that there was but little chance of doing general topographic work, Mr. Thompson devoted the early part of the season to a detailed survey of Mount Shasta and its immediate surroundings. He gathered material for a map of the greater part of that volcanic mass, upon a scale of 1:20,000. In the progress of the work, Mr. Thompson succeeded in taking his pack-train within about 2,000 feet of the summit of the mountain, while he, with his assistant and their riding-animals, succeeded in reaching the summit of the mountain. About the middle of October, the smoke having cleared so that it was possible to engage in general work, Mr. Thompson gave up his detailed work and made a short but very successful trip to the eastward of the mountain, gathering material for the general map. Storms, however, set in towards the latter part of the month, which made it necessary to leave the high country, when he returned to headquarters, called in Mr. Kerr's party, and abandoned field-work for the season.

During the winter, Messrs. Thompson, Kerr, and Noerr have been engaged in computing and platting field-notes and in compiling maps for the use of the geologists, from land-survey plats. Altogether, including the detailed survey of Mount Shasta, about 4,000 square miles

were mapped. By the aid of the work of this and last seasons, together with the material obtained from Land Office plats, a field map, covering about 24,000 square miles, has been compiled, upon a scale of 2 miles to an inch, for the use of the geologists.

DETAILED WORK IN CALIFORNIA.

The survey of the quicksilver deposits of California, by Mr. J. D. Hoffman, with the assistance of Mr. C. C. Bassett, which was in progress at the beginning of the last fiscal year, has been carried on during the greater part of the past year, and was completed about the close of April. The results of this work are as follows: A map of the Sulphur Bank District, comprising an area of 3 miles by 4, or 12 square miles, on a scale of 800 feet to an inch, in contours 20 feet apart; a map of the New Almaden District, comprising an area of 20 square miles, on a scale of 800 feet to an inch, in 20-foot contours; a map of the Knoxville District, comprising $8\frac{1}{4}$ square miles, on a scale of 800 feet to an inch, in contours 25 feet apart; and a map of the New Idria District, comprising 12 square miles, on a scale of 800 feet to an inch, in contours 40 feet apart vertically.

Upon the completion of this work, Mr. Hoffman was ordered east, for the purpose of platting the general topographic work done by him in 1882, while connected with the California division, upon which work he has since been engaged.

Besides the regular office work, incident to platting the field-notes, transferring plane-table sheets, and geodetic and barometric computations, the compilation of a map of the United States, upon a scale of 16 miles to an inch, has been commenced and is being rapidly pushed forward, almost all of the material for its construction being at hand or easily accessible.

During the field season, or at its close, the following men, all of whom had been employed temporarily only, resigned their positions on the Survey: H. L. Dawes, J. D. Colt, F. M. Boteler, S. R. Duval, T. W. Birney, Edmund Shaw, R. T. Varnum, W. S. Renshawe, R. M. Towson, R. D. Shepard, A. B. Heyl, J. S. Happer, and Thorburn Reid.

I am, very respectful y, your obedient servant,

HENRY GANNETT,
Chief Geographer.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. ARNOLD HAGUE.

UNITED STATES GEOLOGICAL SURVEY,
YELLOWSTONE NATIONAL PARK SURVEY,
New York, July 1, 1884.

SIR: I have the honor to present the following report of field and office work under my charge for the year ended June 30, 1884:

Field operations for the year were almost exclusively confined to the Yellowstone Park. Early in the month of July, under your instructions, I left New York, proceeding to Bozeman, Mont., to organize a camp adequately equipped for several successive seasons of field-work in the Yellowstone Park and adjacent regions of Wyoming and Montana. From Bozeman I proceeded by the main wagon-route to the Park, and after stopping for two days at the Mammoth Hot Springs, I traveled by slow marches, making preliminary geological examinations along the route, to the Upper Geyser Basin, where I established the first permanent camp for the season on the east bank of the Fire Hole River, just above Old Faithful Geyser.

The party of professional assistants was constituted as follows: Messrs. Joseph P. Iddings, Walter H. Weed, George M. Wright, and C. D. Davis, assistants in geology; Dr. William Hallock, physicist employed in making a special study of the physics of geyser action; Mr. W. H. Jackson, photographer; Mr. Rheinhart, assistant photographer; and Mr. Roland Holt, volunteer assistant.

Owing to the lateness of the season for commencing field-work, I decided to confine the work mainly to preliminary examinations of the volcanic field and the closely related problems of thermal activity displayed on such a gigantic scale throughout this region.

In studying the volcanic phenomena, I desired to find out the varieties of rock represented, their areas and their relations to each other. Nearly all of Mr. Iddings's, as well as a large share of Mr. Wright's time, was devoted to these questions. All the time at my own command, not occupied in investigating the phenomena immediately connected with the geysers and hot springs, was given to a study of the relation of the rhyolite extrusions to the great centers of thermal activity. In this connection I was anxious to determine the source, the extent, and, so far as possible, the thickness of the great rhyolite flows which cover such immense areas and form the main body, if not all, of the Park plateau.

This study required extended and laborious travel, and in the prosecution of the work I visited Mount Sheridan, Mount Chittenden, and the volcanic region in the neighborhood of Mount Washburne.

Mr. Weed was almost exclusively occupied in making careful examinations of the present condition of the thermal springs and geysers, and in collecting a complete suite of specimens illustrating nearly every

form of deposition and mode of occurrence of the travertine and geyserite. His comparative study of the conditions of thermal activity in the summer of 1883, which were also observed by Dr. A. C. Peale in 1878, will be of great interest and scientific value. Dr. Peale's work laid the foundation for a thorough and scientific study of the thermal springs, which I hope to prosecute for several consecutive seasons, and in this connection I wish to bear testimony to the general accuracy of his report and to his indefatigable industry in the collection of his data. A study of the geyser basins shows but few changes of importance and fails to confirm the opinion frequently expressed that there is a decided falling off in the intensity of thermal action within the last ten or twelve years. To the list of active geysers in the Lower Geyser Basin, given by Dr. Peale, I have only one to add, and even this one he suggested might prove to be a geyser. It is situated on the broad sinter plain to the northwest of the mound of the Fountain Geyser and a short distance south of the main road. It presents a large gray pool nearly 100 feet in diameter, but is not noticeable for beauty of form or of color. Near the west border of the pool there is a narrow vent over which the water, owing to its greater depth, shows a dull-green color. This geyser I have named the Surprise; from the height and diameter of the column and the force displayed it will rank as the third geyser in the Lower Basin. I have also to add one new geyser to those already reported in the Upper Basin. It is situated in the Emerald Group. I have named it the Cliff Geyser, as it lies so close under the abrupt wall which skirts the west bank of Iron Creek.

Dr. Hallock's investigation of the physical aspects of geyser action yielded most interesting results, which when published will be found to be of great scientific value. He was mainly occupied with questions of subterranean temperatures in the geyser pipes and reservoirs, using both maximum thermometers and thermo-electric methods. The investigation necessarily presented many difficulties which could not be foreseen till experimental work had determined the character of the geyser reservoirs. This preliminary survey of the geysers and geyser springs to ascertain the depths of the geyser pipes, forms of basins, force of discharge, and intervals of rest, consumed a large amount of time. The coming year Dr. Hallock goes out prepared to overcome certain obstacles, thoroughly understanding the difficulties he has to surmount. He takes with him a new maximum thermometer especially adapted for this work, and will employ improved methods for insulating the wires at the higher temperatures in his thermo-electric experiments. His investigations, although covering a large number of geysers, were mainly conducted upon "Old Faithful," the "Giantess," "Grand," and "Beehive."

Mr. W. H. Jackson and his assistant joined me in the Lower Geyser Basin and remained till near the close of the field season. Mr. Jackson was eminently successful with his pictures, surpassing my highest ex-

pectations, and in his own opinion accomplished more satisfactory results than in any other season during the fifteen years in which he has been actively engaged in photographic work in the Rocky Mountains. His intimate acquaintance with the Park enabled him to make use of his time to the best advantage. The collection of views is quite extensive and is represented by four sizes of negatives and a set of nearly one hundred stereoscopic pictures. The large views (18 by 22 inches) are in the highest style of photographic art. The complete set of views of the geysers and hot springs will be of great scientific value, for purposes of illustration in the final reports.

Valuable as the Yellowstone National Park undoubtedly is as a national reservation, to be forever set aside and held as a place of recreation for tourists who can afford the time to enjoy the advantages of a few weeks of rest and recreation among some of the grandest and most weird scenery of the Rocky Mountains, and desirable as it is that the incrustations and sediments around the geysers and hot springs, and all objects of scientific interest, should be carefully preserved, there are, I think, other reasons why the Park should be maintained, quite as important as those usually assigned.

First in importance comes the protection of the forests which occupy such large areas on the Park plateau and densely cover the adjacent mountains. Few regions in the Rocky Mountains are so highly favored as regards snow and rainfall. Snow falls early in October and rarely disappears before June, and throughout the winter it is said to lie 6 feet in depth over the plateau and the higher regions of the Park. The Park is peculiarly well adapted for holding broad sheets of water. In consequence we find here such bodies of water as the Yellowstone, Shoshone, Heart, and Lewis Lakes, besides innumerable smaller ones. These lakes are the natural reservoirs for storing up the water-supply. The Yellowstone Lake alone has an area of 150 square miles, and is the source of the Yellowstone River, which drains into the Mississippi; while the Shoshone empties into the Snake River, reaching the Pacific through the Columbia. Forests cover the hills to the water's edge. The timber retains the snow late in the season, while it slowly melts away and fills the springs and lakes. If the forests are removed, the snow will rapidly disappear under the direct rays of the sun and by evaporation, and it will be largely carried off by the dry west winds which prevail. There would be enormous freshets in the spring, followed by a long parched season, the lakes and springs rapidly diminishing. For these reasons I wish not only to see the forests within the present limits of the Park rigidly maintained, but also that the boundaries of the national reservation should be considerably enlarged to the south and east.

By including with the Park area the broad range of mountains to the eastward of the present boundary, a dense timber region will be forever secured, which carries many large streams flowing both east and west, finally emptying into the main valley of the Yellowstone. If the broad

valley of the Yellowstone is ever to support any considerable population, the forests and streams from these elevated regions must be protected. The Yellowstone Valley can stand no diminution in the water-supply which it now receives.

Next to the maintenance of the Park forests the second object of importance is the preservation of game. The Park, to become a national game reservation, should be enlarged to take in the lands to the south and east, which are natural haunts of the elk and deer, and which are regarded by hunters and trappers as amongst the best game regions in the Rocky Mountains. The country around the geyser basins was never a favorite resort of large game, and the bare volcanic region lying between the geyser basins and the Yellowstone Lake affords too little grazing ground for any large number of deer and elk. In enlarging the Park by including well-known resorts of the larger game, the whole region becomes a natural zoölogical reservation for all wild animals driven in from the surrounding country for protection. If in the Yellowstone Park the large game are properly protected by officially appointed, intelligent gamekeepers and assistant superintendents, they will rapidly increase in numbers, and, according to all laws of nature, in time the excess would be forced from this place of security into the adjoining mountains, affording ample pleasure for a long time to come to the true sportsman and tourist, whose shooting would be under the restriction of game laws.

Throughout August and September the weather remained exceptionally fine, but from October first till the time when the party finally left the field there was not a single day in which we were not delayed by storms more or less severe.

I returned to the Mammoth Hot Springs September 30, after spending two months on the Park plateau, with headquarter camps at the geyser basins, Yellowstone Lake, and Grand Cañon.

From the camp at the Mammoth Hot Springs I undertook a trip across the northern part of the Park, accompanied by Mr. W. H. Weed, with the intention, first, to make a geological reconnaissance across the Yellowstone range, and second to visit the Clarke's Fork mines for the purpose of learning their position in relation to the Park boundaries, and to ascertain the extent to which mining operations had already been carried. Before the completion of this journey the snow-storms were so frequent and violent as to stop all active field-work. The weather remaining unfavorable for geological work, I finally decided to break camp, and on October 23 most of the party, including myself, left the Mammoth Hot Springs for the East.

Mr. C. D. Davis remained to forward the collections, and to see the camp equipage safely stored in Bozeman, with instructions to return east on the completion of his duties.

At the close of the season Mr. J. P. Iddings left for Nevada and Utah under instructions to examine one or two localities of especial interest in our study of volcanic rocks of the Great Basin. Among other

localities he revisited Eureka, and while there he collected several sets of two hundred specimens each of typical rocks found in the district. They include Paleozoic quartzite and limestone, and three varieties of volcanic rocks, namely: hornblende-andesite, dacite, and rhyolite. They will form a valuable portion of the two hundred suites of characteristic rocks, now being prepared under your instructions for distribution to institutions of learning.

During the winter and spring office-work has progressed steadily, the time being employed in writing out field-notes and in working up the material gathered the preceding summer in the Yellowstone Park. In addition to this work, Mr. Iddings and myself have given considerable time to our work on the volcanic rocks of the Great Basin—a work which has grown upon our hands and assumed proportions by no means anticipated when we began the investigation. During the year, in connection with this work upon the Tertiary and post-Tertiary volcanic rocks of the Great Basin, I have published jointly with Mr. Iddings two brief articles in the American Journal of Science and Arts. The first appeared in September, 1883, entitled "Notes on the Volcanoes of Northern California, Oregon, and Washington Territory." The second paper was published in June, 1884, under the title "Notes on the Volcanic Rocks of the Great Basin."

On April 1, Dr. F. A. Gooch entered the chemical laboratory of the Geological Survey and has made the chemical investigation of the waters, incrustations, and sediments connected with the geysers and hot springs. In obtaining the services of Dr. Gooch for this important work, I feel that the corps has been greatly strengthened.

I regret to say that my work upon the report on the Geology of the Eureka District has not progressed as rapidly as I could wish. This is due in part to the pressure of other work, but mainly from an unwillingness to complete the monograph before obtaining the results of the investigation of the volcanic rocks, since igneous extrusions play so important a part in the geological history of the Eureka District.

The monograph of Mr. Charles D. Walcott on the "Paleontology of the Eureka District" is completed and ready for the printer. In my letter to you, transmitting the report of Mr. Walcott, I have taken occasion to express the very great value I place upon his work and its important bearing upon the geology of the Basin ranges.

In closing this letter I desire to express my thanks to the trustees of the American Museum of Natural History for the facilities which they have afforded us during the past year, in placing at our disposal, free of rent, two large working rooms. Their library and collections have been of great service in our work.

Very respectfully, your obedient servant,

ARNOLD HAGUE,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. T. C. CHAMBERLIN.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF QUATERNARY GEOLOGY,
Beloit, Wis., June 30, 1884.

SIR: I have the honor to submit the following report of field and office work under my charge during the fiscal year ending June 30, 1884:

The 1st of July found work in progress in two of the fields occupied during the year, the driftless area of the upper Mississippi Valley and the drift border in the Missouri Valley, in Dakota, the former under Prof. R. D. Salisbury, the latter in my personal charge.

The ends sought in the investigation of the driftless area were set forth in my last adminstrative report. The earlier examinations of the present year were a continuation of those already inaugurated. As the work progressed, the range of subjects was somewhat amplified, and the territory was broadened.

The original purposes were mainly three: (1) By a critical study of the residuary clays, to fix a standard of comparison between the disintegration products of subaerial agencies and the mechanical products of glacial action; (2) by a study of non-glaciated topography to furnish a necessary element in the estimation of the amount of planation, or accumulation, or both, necessary to produce a surface analogous to that of the adjacent drift-covered regions, and thus approach a quantitative estimate of the drift; and (3) by a determination of the amount of residuary clay and other loose disintegration products, to furnish an element in the computation of its quantitative relations to the receptive capacity of the topography, and to the total mass of the drift.

In the observations bearing directly upon these subjects, which embrace about 2,000 specific measurements, there fell under attention, also, the following studies: (*a*) The character and location of the border of the drift surrounding the driftless area; (*b*) the subaqueous clays bordering the Mississippi River and west of it in that region; (*c*) the valley and high-level gravels of the Mississippi and its tributaries; (*d*) the river terraces, and (*e*) the distinctive character of the valleys.

Mr. Salisbury's work upon these subjects was distributed as follows: The 1st of July found him in the vicinity of Platteville, Grant County, Wisconsin. His lines of observation lay in this county during the earlier part of the month, and during the later part of the month in Jo Daviess County, Illinois. In early August he passed into Iowa at Dubuque, and occupied the earlier part of the month in observations along the west side of the Mississippi, from that point north to the mouth of the Wisconsin River. Later in the month he re-entered Wisconsin, and carried a belt of observations across Crawford, Richland, and Sauk

counties, and along the drift border in Dane and Green counties. In September his work lay mainly in Dunn, Pepin, and Chippewa Counties, and subordinately in Monroe, La Crosse, and Jackson. In October he examined selected portions of Clark, Wood, Trempealeau, and Buffalo counties, Wisconsin, and Wabash, Winona, Olmsted, Fillmore, and Houston counties, Minnesota.

In the early part of November, I diverted Mr. Salisbury, temporarily, from his special line of work, to aid in the completion of some observations on the Glacial deposits in northwestern Indiana and northeastern Illinois lying in the line of my own special work of morainic correlation, but which other duties prevented me from finishing personally.

In the latter part of November, Mr. Salisbury resumed work on the residuary products, in Missouri, this being a part of the plan to extend such studies around the periphery of the drift region, with a view to a wider and more trustworthy basis of comparison.

Incidental to this dominant theme, the loess and loess-like deposits along the Missouri River, the drift border, and the valley gravels, fell under consideration. The work embraced selected portions of Jefferson, Washington, Franklin, Phelps, Gasconade, Osage, Cole, Moniteau, Pettis, and Cooper counties.

The work in southern Dakota, under Prof. J. E. Todd, was an extension of that previously done, an outline of which has been given in preceding annual reports, to which I beg leave to refer. While the leading object has been to trace out the system of marginal moraines, and determine the salient character of the Glacial movements, a considerable number of accessory themes have received attention.

Professor Todd, with Mr. Wm. Ellis as assistant, started from Tabor, Iowa, to his field on July 10, and on the 14th, having completed his equipment, began his investigations at Chamberlain, Dakota. The remainder of the month of July was devoted to tracing the outer moraine of the later Glacial epoch, from the vicinity of Bijou Hills, southeastward, to the southern border of Dakota, and the examination of some points in the adjacent portion of Nebraska. The special subjects that fell under attention were: (1) A range of drift hills lying along the northeast side of the Missouri River stretching from Platt Creek nearly to the mouth of the Missouri; (2) a series of Glacial outlet valleys traversing these; (3) the western limit of bowlders on the north border of Nebraska; (4) the deep loess deposits, capping the highlands south of the Missouri River, in Knox County, Nebraska, and the contrasted stony drift on the opposite highlands north of the Missouri; (5) the morainic, interlobate accumulations of the Chateau Creek Hills and Turkey Ridge, and (6) their former drainage system.

The months of August and September were employed in carrying lines of observation to and fro across the Coteau, between the Missouri River and the James River, in latitude varying from below 45° north to 47° north. About one week was occupied in each traverse. The prime object

of this work was the location and general determination of the complex system of morainic tracts that characterize this portion of the Missouri Coteau. There fell under attention, also, the following subsidiary subjects: (1) The remains of an extensive post-Glacial forest growth in Douglas and adjoining counties; (2) a region nearly free from till, between American and Crow Creeks; (3) a line of osar ridges stretching southeast from Crow Lake; (4) an internal Glacial drainage system among the Wessington Hills, and a similar system among the Ree Hills; (5) the Great Ree Valley, determined to be the track of an ice-lobe; (6) several inter-lobate accumulations in Sully County; (7) a driftless, or, at least, till-less area in southeastern and central Potter County; (8) the Bald Mountains, considered an inter-lobate moraine; (9) two lobate tracts, formerly occupied by ice-tongues, north of the Bald Mountains, one of which crosses the Missouri River, and a third one in the valley of Long Lake; (10) several re-entrant moraines and inter-lobate areas associated with these; (11) the great moraines on the elevated Coteau; (12) a looped line of scattered morainic hills (third moraine) in Faulk, Hand, Beadle, Brown, Le Moure, and Stutsman counties.

The topography, water supply, native vegetation, and pre-Quaternary deposits were also subjects of observation.

The first week of October was occupied in some examinations in southeastern Dakota, supplementary to those of previous years; among these were some further observations on the Mitchell moraine, an examination of some extensive *roches moutonnées*, 7 miles north of Alexandria, the basin-bearing tract north of Canton, the loess-capped highlands east of the Big Sioux River, the draining features near Sioux Falls, and the outer moraine near Madison. Professor Todd returned from the field on October 8. He was engaged a portion of the remainder of the year formulating the report of his results, and constructing maps, sketches, diagrams, and tables to accompany it.

In my individual work I was overtaken by the unfortunate midsummer transition of fiscal years at the Brulé Agency, on the Missouri River, in southern Dakota. As indicated in my last administrative report, I was engaged in a preliminary determination of the character and limits of the drift in the upper Missouri Valley. The plan contemplated making the Missouri River a base of operations, whence lines of observation were to be extended westward at such points as were found practicable and deemed necessary to the determination of the salient features of character and distribution, and the judicious formulation of the more exhaustive working plans contemplated in the future. The restiveness of the Sioux Indians over an apprehended reduction of their reservation rendered extensive examinations in their territory injudicious, and, under the advice of Indian agents, my excursions were confined to routes and methods least liable to excite attention. A trip from the Lower Brulé Agency to Medicine Butte and vicinity had been finished on the last

day of June. Transferring thence, via Mitchell and Huron, to Pierre, a trip was made west of the Missouri River along the Black Hill's stage route, a distance of 45 miles, or some 25 miles beyond the last observed drift of northeastern derivation.

Through the personal kindness and assistance of Maj. J. McLaughlan, agent at Fort Yates, I was permitted to reconnoiter the drift area west of that point. From the line of the Northern Pacific Railway I was enabled to extend observations with more facility. My reconnaissance in that region was closed July 14.

Pursuing the plan of comparative studies, I next zigzagged broadly the border of the drift in southern Illinois, and thence eastward through Indiana, Kentucky, and Ohio to the Scioto Valley.

There I resumed the study of some of the more doubtful portions of the border of the later drift, under the advantages gained by the familiarity with the older marginal belt, which the preceding studies and those of earlier date had given. With a brief interruption, incidental to attendance upon the meeting of the American Association at Minneapolis, and the subsequent examination of the osar ridges in Ogle County, Illinois, described in the report of that State and considered morainic, this work was pursued until the 1st of November. As previously reported, throughout the plain region of northeastern Illinois, central Indiana, and western Ohio, the marginal accumulations of the later ice sheet are less conspicuous and unequivocal than in the regions of greater topographic relief, east and west. A large amount of critical study will be needed for a complete demonstration of the precise history of the Glacial movements of that region, and the delineation of the peripheral accumulations that mark successive stages. As an additional step toward this, a belt passing in a sinuous course through the following counties was reconnoitered: Ross, Highland, Clinton, Fayette, Greene, Madison, Clarke, Champaign, Logan, Miami, Montgomery, Preble, and Darke, in Ohio; and Wayne, Randolph, Henry, Rush, Decatur, Jennings, Bartholomew, Johnson, Morgan, Hendricks, Montgomery, and Tippecanoe, in Indiana.

During November, leave of absence was granted me, during which, however, I prepared a portion of the above observations for publication. In early December, the weather continuing favorable, I did some field-work on the continuation of the above border-belt in northeastern Illinois. The remainder of the year, aside from local observations that do not need record here, has been devoted to office work. Besides the elaboration of field results, I have gathered and tabulated for publication, as a bulletin of the survey, all accessible records of glacial striation in the United States. I have also prepared for publication in your Fifth Annual Report a discussion of the requisite and qualifying conditions of artesian wells, and, by your permission, have published in the American Journal of Science the results of some of

my observations on a significant class of angular, calcareous sands and gravels heaped in kame-like hillocks, and characterized by disturbed stratification.

Very respectfully, your obedient servant.

T. C. CHAMBERLIN,
Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF PROF. ROLAND D. IRVING.

UNITED STATES GEOLOGICAL SURVEY,
Madison, Wis., June 30, 1884.

SIR: I have the honor to submit the following report of operations in the division of the survey under my charge for the year ending June 30, 1884.

The work of this division is a general investigation of the Archæan Formations of the Northwestern States.

FIELD-WORK.

The field-work of the year has been carried on by five independent parties.

The first party, under my immediate charge, was occupied during the month of July in a general study of the rock series of the Marquette and Menominee iron regions of Michigan and Wisconsin. In this work I was aided by Assistant Geologists C. R. Vanhise and W. N. Merriam, whom I kept in my immediate party, not only for the sake of their aid, but also and chiefly because, wishing them to conduct independent parties during the season of 1884, I was desirous to have them first obtain as broad an acquaintance as possible with the formations they were to study. My own object in visiting these regions at this time was also to extend my previously slight acquaintance with them sufficiently to enable me to compare them intelligently with the other supposed Huronian areas, and to determine the extent and nature of the detailed work to be hereafter done here. Since much descriptive and mapping work had already been done in these regions by Brooks, Wright, Rominger, and others, and since they are quite thoroughly opened by wagon road and railway, we were enabled to see all important exposures and to gather a large and thoroughly representative collection of the rocks here displayed. Besides the obtaining of a general acquaintance with these

classical and difficult regions, we were able also to devote a good deal of attention to points of special interest as bearing upon problems in genesis and structure, as for instance the relation of schists to massive greenstones, the origin of the jaspery schists and associated iron ores, the relations of the iron-bearing to the older gneissic formation, and the general stratigraphy of the series. In studying these questions we made a point of seeing, with the various previously published descriptions in hand, each one of the several groups of rocks into which the series has been divided by various authorities. Our work included also careful study of the relation of the sandstone to the underlying peridotite in the classical locality of Presque Isle near Marquette.

On the 1st of August this party was transferred to the Sault Ste. Marie, Michigan, with the object of examining the exposures in this vicinity of the formation to which the term Huronian was originally given by the Canadian geologists. Three weeks were spent in this vicinity, during which time we obtained a thorough acquaintance with the original Huronian and with each one of its subordinate divisions as indicated on Logan's original map.[1]

In the latter part of August the party, with the exception of Mr. Vanhise, was transferred to the boundary line between the United States and Canada northwest of Lake Superior; Port Arthur, on the Canadian shore of Thunder Bay, becoming our base of supplies. The objects of our studies were the obtaining of a more thorough acquaintance with the so-called Animikie Series of this region, and the making of an examination of the contacts of this series with the more northerly rocks. From Port Arthur the party, consisting of Mr. Merriam and myself and two packers, or canoemen, was transferred, with canoes and supplies, by tug to Grand Portage Bay, on the Minnesota coast. Procuring here an additional canoeman, we crossed the "Grand Portage," 9 miles, to Pigeon River, followed that stream to South Fowl Lake, passed thence through South Fowl, North Fowl, Moose, Mountain, Rove, Mud, South, North, and Gun Flint Lakes, to the passage from the latter lake to Lake Saganaga. At South Lake we met Mr. Chauvenet's party, subsequently spoken of, and the vicinity of Gun Flint and North Lakes was examined in his company. We then returned slowly eastward, examining more in detail the rocks that we had noted only cursorily before. At Grand Portage one of our packers was dismissed, and the 50 miles on Lake Superior between that point and Port Arthur was then traversed in the bark canoes. From Port Arthur the party returned to headquarters at Madison, which was reached at the end of September.

In the mean time Mr. Vanhise, who had parted from us at the Sault Ste. Marie, had made some additional investigations assigned to him in that vicinity, had then proceeded to the Michigammi and Republic Mountain districts in Michigan, to make a special study of those local-

[1] Atlas to Geology of Canada 1863, Plate III.

ities, and had thence returned to Madison, which he reached early in September.

In the latter part of October, in company of N. H. Winchell, the State geologist of Minnesota, I made my first acquaintance with the quartzites of southern Minnesota as exposed at New Ulm and Red Stone in the Mississippi Valley and in the northern towns of Cottonwood County.

The second party, under Prof. C. W. Hall, of the University of Minnesota, consisting of himself and one assistant, Mr. C. F. Sidener, was occupied during July and August in an examination of the granitic and gneissic rocks of Stearns, Morrison, and Todd counties in central Minnesota, and the quartzites of Red Stone and New Ulm in the Minnesota Valley. This party moved about during the season by team, camping wherever their work took them. Since the close of the field-work, Professor Hall has been occupied, as his professional duties allowed, in elaborating his notes.

The third party, in charge of W. M. Chauvenet, was occupied in Minnesota and along the national boundary line, northwest of Lake Superior, during the months of August and September. The special objects of his work were (1) the obtaining of one or two cross sections of the country north of Grand Marais from the lake to the folded schists of the boundary line in the vicinity of Knife Lake, and (2) the examination of the region about Knife and Kingfisher Lakes, with the view of determining the relations of the Animikie in this region to the more northerly folded schists.

Mr. Chauvenet, leaving Grand Marais with three Indian packers and two canoes, portaged by the Rove Lake trail, 7 miles to the first lake on the western part of T. 62, R. 1 E. Thence his course lay through Tamarack Lake in Secs. 12 and 13, T. 62, R. 1 W., and thence northward by stream and portage through the central part of T. 63, R. 1 W., to the Brulé River, which he reached in Sec. 14, T. 63, R. 1 W. From the last point that stream and the lakes connecting with it were followed to the northwestern corner of the town, when the course lay principally westward through the unsurveyed townships in T. 64, to Agamok Lake at the adjoining corners of T. 64 and 65, R. 5 and 6 W.; thence through Kingfisher Lake and its numerous ramifications in T. 65, R. 6 W.; thence into Knife Lake, and thence along the national boundary to the western end of Basswood Lake, on the west side of R. 9 W., which was the westernmost point of the trip. Returning now to Knife Lake the rocky shores of the numerous ramifications of that lake were examined, after which the course was along the boundary line through Saganaga Lake and through the various lakes and streams south of it to Gun Flint Lake, in T. 65, R. 3 W., the several southern prolongations of Lake Saganaga and Sea Gull Lake, in T. 65, R. 4 and 5 W., being visited on the way by side excursions. From Gun Flint Lake Mr. Chauvenet moved eastward, examining the rocks exposed on Loon, Iron, North, Clear Water, Pike, Pine, and McFarland Lakes. From the last-named lake the course lay

to Grand Portage, and thence by tug to Grand Marais, where the party was disbanded.

The fourth party, consisting of Prof. W. W. Daniells, and such assistants as he found it necessary from time to time to employ on the ground, was occupied during the months of July and August in extending the work done by the Wisconsin survey upon the crystalline rocks of Waupaca, Wood, Marathon, Shawano, Lincoln, and Langlade counties, examining and sampling such ledges as could be found in addition to those previously known. The object of this work was the collection of further evidence to aid in working out the distribution and structure of the rocks of a difficult district.[2]

The fifth party, consisting of Mr. W. N. Merriam, and such assistants as he found necessary to employ on the ground, has been occupied during the latter part of May and June of the present year in studying the quartzites of southeastern Dakota, where he has found a large number of hitherto unknown exposures.

OFFICE-WORK.

The office-work of the year included microscopical rock studies, drafting, photography, preparation of matter for publication, and general studies of results.

Lithological work.—Microscopic work has continued throughout the year, my principal assistant in it having been Mr. Vanhise.

During the year some 775 thin sections have been added to our collection, of which 127 have been made at the Washington office of the Survey, and the remainder at Madison. Written descriptions have been prepared of 354 of these during the year, the total number of written descriptions made since the beginning of our work, September 1, 1882, being 459. Of the latter number 450 are of sandstones and quartzites, 81 of greenstones (including diabases, gabbros, norites, diorites, &c.,) 34 of mica-schists and chlorite-schists, 12 of chert-schists and jasper-schists, 14 of amphibolite-schists, 20 of greywackes, 14 of gneiss, 12 of clay slates, 4 of limestones, 12 of granites, and 2 each of augite-schists and felsitic porphyries.

Drafting.—Much of Mr. Merriam's time during the year has been occupied in drafting. He has made 34 colored and 4 uncolored drawings of rock sections from the microscope for publication. He has also drawn for the Fifth Annual Report of the Survey a preliminary general geological map of the Northwest, besides two large-scale working-maps for platting the field-work. In addition to these he drew, during the winter, in the note-books on file, a large number of small maps illustrative of the field-work.

[2] Geol. Wis., Vol. IV, pp. 625–712.

Photography.—During the year we have taken in the field some 80 photographic views. The negatives of these views, generally in duplicate, Mr. Merriam has developed in the office during the winter months, besides printing from them a number of proofs. Mr. Merriam has also devoted some time to the photographing of rock sections, in which he has attained sufficient proficiency to enable him to prepare such photographs for publication.

Publications.—During the year we have prepared an illustrated paper, "On secondary enlargements of mineral fragments," to appear as Bulletin No. 8 of the Survey, and also a "Preliminary paper on the Archæan formations of the Northwest," for the Fifth Annual Report of the Survey. Besides these, papers have been published in the American Journal of Science, upon the "Paramorphic origin of the Hornblende in the crystalline rocks of the Northwest" by myself, and on "Secondary enlargements of feldspar fragments in certain Keweenawan sandstones by Mr. C. R. Vanhise.

Mr. W. N. Merriam is the only assistant on my division of the Survey who has been employed constantly throughout the year. The following have been employed on a per diem, at such times as their services were needed: Assistant geologists, C. R. Vanhise, C. W. Hall, W. W. Daniells, and W. M. Chauvenet; and as office assistants, E. A. Birge, T. W. Haight, N. M. Thygeson, T. A. Polleys, H. Fehr.

I am, with respect, your obedient servant,

ROLAND D. IRVING,
Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF DR. F. V. HAYDEN.

UNITED STATES GEOLOGICAL SURVEY,
Philadelphia, Pa., July 1, 1884.

SIR: I have the honor to submit herewith a brief summary of my work under your direction for the fiscal year ending June 30, 1884 accompanied by a preliminary report of the operations of Dr. A. C. Peale and myself in the Upper Missouri region during the field season of 1883.

The field-work undertaken during the fiscal year consisted of a reconnaissance along the line of the Northern Pacific Railroad, from Bismarck, Dak., westward to Helena, Montana. This work was merely preliminary to a more thorough examination which it is hoped may be accomplished in the future, especially in connection with the more or less isolated ranges which are found in the region between the Yellowstone and Missouri Rivers, east of the main ranges of the Rocky Mountains.

It consisted mainly of a study of the stratigraphical relations of the beds of the Laramie Group and the Cretaceous immediately underlying it, as they are shown in exposures between the Missouri at Bismarck, Dak., and the Yellowstone at Glendive, Mont., and along the river from the latter point to Livingston.

The sands, clay, and coal beds of the Laramie Group (or Fort Union Group), form the surface formation throughout most of this area; the Fort Pierre and Fox Hills Groups of the Cretaceous showing only at a few localities.

Bismarck was reached the latter part of July, and a study of the immediate vicinity was at once begun. A section of the rocks passed through by the artesian well being sunk there was obtained and the railroad cuts near the bridge across the Missouri River were examined. A trip was also made to Sims, 40 miles west of Bismarck, for the purpose of visiting the coal mines and brick and terra-cotta works operated there. A collection of fossil plants and shells was obtained at this locality.

Leaving Bismarck, the next stop was made at Dickinson, Dak., where there is an outcrop of coal, which was found to be undeveloped and not well exposed.

Little Missouri, the station at the point where the railroad crosses the Little Missouri River, was next visited. Here sections were made of the bad-land beds, including the coal bed worked by the Northern Pacific Coal Company. The next section was made at Glendive, Mont., where the railroad first reaches the Yellowstone River. From here an excursion was made to Iron Bluff, some 10 miles up the river. The upper Cretaceous rocks so well exposed at that locality were carefully examined.

Billings, on the north side of the Yellowstone, is 225 miles from Glendive, and is the point where the railroad first crosses the river. It was reached August 10. The rocks exposed here are Cretaceous, the black shale of the Fort Pierre Group being especially well shown on the south side of the river opposite the town. On the north the sandstones of the Fort Hills Group form conspicuous bluffs. These were visited and followed some 10 or 12 miles to the westward. A three-days' trip was made to the Bull Mountain coal beds, about 45 miles northeast of Billings. This coal is in the Laramie Group and of remarkably good quality. An interesting collection of fossil leaves was secured from beds above and below the coal.

Leaving Billings August 20, Livingston, Bozeman, and Helena were next visited in succession. At the latter place the Helena Hot Springs were visited, and a rapid excursion was taken over the Mullan Tunnel to what was then the end of the eastern portion of the Northern Pacific Railroad. The Silurian rocks in the immediate vicinity of Helena were also studied.

Returning from Helena, the first stop was at Bozeman, from which

point the Chestnut coal mines, in Rocky Cañon, and the mines near Bozeman Pass were inspected, and collections of fossil plants made from the beds in connection with the coal. The cañon of Bozeman Creek, south of Bozeman, was followed to its source in Mystic Lake, and the relation of the Archæan and superimposed sedimentary rocks studied.

After packing all specimens collected up to that point, and shipping them through the quartermaster's depot at Fort Ellis, Dr. Peale next proceeded to Livingston, where he completed a section begun by him at that point in August. His next stopping place was Springdale, where he crossed the Yellowstone River to Hunter's Hot Springs, at the southern end of the Crazy Mountains. At Stillwater, 45 miles farther down the river, an interesting section in the upper part of the Cretaceous was obtained, after which Billings was again visited for the purpose of examining the artesian-well boring, which had been begun since the previous visit. The next stopping place was the coal mines at Lignite, near Miles City, after which Dr. Peale went to Gladstone, a station in Dakota between Dickenson and Sims. Here a large collection of fine fossil plants was made from the Laramie Group. He then proceeded to Mandan, and after packing the specimens collected during September, and turning them over to the quartermaster at Bismarck for shipment, he returned to the East early in October.

The office-work during the winter months has consisted mainly of the study and revision of the notes of the summer's work.

Dr. Peale has also begun the preparation of a bibliography of the mineral springs and waters of the United States, and has also taken the preliminary steps for making a subject index to the publications of the Geological and Geographical Survey of the Territories. He has also begun a paper on the "Mineral waters of Montana," for which he secured considerable material during the summer while in Montana.

I beg to remain, very respectfully, your obedient servant,

F. V. HAYDEN,

Geologist.

Hon. J. W. POWELL,

Director U. S. Geological Survey, Washington, D .C.

REPORT OF MR. G. K. GILBERT.

UNITED STATES GEOLOGICAL SURVEY,

DIVISION OF THE GREAT BASIN,

Washington, D. C., July 1, 1884.

SIR: I have the honor to submit the following report of field operations and office-work in the division of the Great Basin during the fiscal year ending June 30, 1884.

FIELD OPERATIONS.

Mr. Israel C. Russell, assistant geologist, and Mr. Willard D. Johnson, assistant topographer, have been the only permanent assistants. The field operations were under the immediate direction of Mr. Russell.

The opening of the fiscal year found Mr. Russell and myself at Salt Lake City, and Mr. Johnson in the Mono Basin, California, whither he had been dispatched a few days before to initiate preparations for field-work. Mr. Russell started on the 2d of July and proceeded directly to Mono Lake, where he organized a field party, beginning at once the systematic sounding of the lake. On the 20th he divided his party, placing one division in charge of Mr. Johnson and with the other proceeding to the study of the ancient and modern glaciers of that portion of the Sierra Nevada which drains to Mono Lake. His investigations were also carried slightly to the westward of the summit, so as to include the headwaters of branches of the Tuolumne and Merced.

There has been some question as to whether the bodies of ice which lie at the bases of north-facing cliffs in this portion of the Sierra are true glaciers, and Mr. Russell was fortunately able to observe them under circumstances so favorable that his report clearly demonstrates their actual character. His descriptions and photographs leave no room for dispute, except as to terminology.

Later in the season he continued his study of the Quaternary and post-Quaternary eruptions in the Mono Basin, and their relation to the ancient glaciers and the ancient, expanded lake.

Having completed these studies, he started northward on the 5th of September, and proceeded, by way of Mason Valley, the Carson Desert, Wadsworth, Pyramid Lake, Winnemucca Lake, Black Rock Desert, and Susanville, to Red Bluff, Cal., stopping at numerous points to supplement his earlier observations on the Quaternary lake Lahontan. In the cañon of Walker River he made a study of a system of post-Lahontan displacements. At Red Bluff he disbanded his party, returning immediately to Washington, where he arrived October 13.

Mr. Johnson, after the completion of the sounding of Mono Lake, resumed work on his map of the Mono Basin, and the field-work for this was completed before the end of the season. It portrays a rectangular area, including the hydrographic basin of Mono Lake, and will serve to illustrate, first, the relation of the modern lake to its Quaternary expansion; second, the moraines and other vestiges of the ancient glaciers of the eastern slope of the Sierra, and their relations to the surviving ice-remnants, to the ancient lake area, and to the volcanic eruptions; and, third, a series of associated rhyolitic and basaltic eruptions, which have continued from Tertiary to very recent times.

He prepared also a large-scale map of the Parker Creek moraines, and began a similar map of the Leevining Creek moraines, the completion of which was prevented by the storms of winter.

He left the field late in December and reached Washington early in January.

Mr. Johnson's chief topographic instrument was the plane-table, his method being that of trial sketching and correction by intersection. No base line was measured, but scale, azimuth, and geographic co-ordinates were determined by means of a secondary triangulation which was made to include a number of points established by the United States Coast and Geodetic Survey. Relative altitudes were determined within the area of the map by angulation, and a datum for absolute altitude was established by a line of levels connecting Mono Lake with a bench on the Carson and Colorado Railroad.

Mr. Russell and Mr. Johnson received material assistance in the field from Ensign John B. Bernadou, U. S. N., who reported to Mr. Russell at Salt Lake City, and continued with his parties until the disbanding at Red Bluff.

I left Salt Lake City on the 3d of July, and spent a few weeks in the Bonneville Basin supplementing the observations of former years, after which I visited the Lahontan and Mono Basins for the purpose of familiarizing myself with the work performed there by my assistants. My points of observation included Tooele and Stockton, near Salt Lake City, the cañon of Ogden River, Bannack Pass (reached by wagon from Kelton, Utah), Elko, Carlin, Rye Patch, White Plains, and Wadsworth, on the line of the Central Pacific Railroad, Karnak Crest, Humboldt Lake, and Pyramid Lake. I then joined Mr. Russell and traveled with him during the first half of August in the Mono Basin and the Sierra Nevada.

An excursion was afterward made to Lone Pine, Cal., for the purpose of observing the geological work accomplished by the earthquake of 1872, and a day was spent at Carson, Nev., in the examination of the celebrated locality of fossil foot-prints. Returning eastward I stopped at Salt Lake City to complete some business connected with the closing of the Salt Lake office of the Survey, and reached Washington September 10.

Mr. R. Ellsworth Call accompanied me during the month of July, and was thus enabled to acquaint himself with the geologic relations of the fresh-water shells of the Bonneville and Lahontan strata. Returning east from Wadsworth he stopped at Salt Lake City and at Utah Lake, at which points he made collections of recent shells.

Pursuant to your instructions the field operations of the division were brought to a final close at the end of the season. The animals, equipage, furniture, and other material remaining on hand were turned over to other divisions.

While I realize fully the considerations which led to the closing of this investigation of the Great Basin, and while the wisdom of your decision is unquestioned, I yet find myself unable to lay the work aside without a tribute of regret and the expression of a hope that it may

some day be resumed by another if not by myself. I am prone to believe that the results already attained have a greater scientific value than those whose possibility allures to continued exploration, but there remain at least three lines of inquiry which can be followed with great profit if the field is at some future time reoccupied.

The first of these is the economic study of the brines of the Great Basin and of the desiccation products deposited in the playas. Salt, borax, and the commercial alkalies are now manufactured to a slight extent, but the industry would be greatly stimulated and increased by a special chemical and geological investigation, and for this work the study of the ancient lakes has performed the service of a reconnaissance.

In the second place, the study of the Quaternary lakes has been practically restricted to the northern portion of the Great Basin, and the resulting discussion of geologic climate is therefore based upon phenomena having a narrow range in latitude. It is known, however, that there were Quaternary lakes in the southern portion of the Basin, and there was at least one lake in an independent basin in New Mexico. If the histories of these were developed so as to be available for comparison with the histories of Lakes Bonneville and Lahontan it is probable that great advantage would accrue to the study of climate.

A third subject for future research is deformation. A small number of measurements have served to show that the Bonneville shore-line and its companion the Provo shore-line are at the present time neither parallel nor level, and the same measurements suggest that there is an element of system in their deformation. It is a plausible hypothesis that one of the factors concerned in the local deformation of the earth's crust was the removal of the weight of the water contained in the lake, but existing data serve only to suggest this hypothesis and not to demonstrate it. If measurements were multiplied so as to exhibit in a complete manner the deformation of the ancient horizons of water-level in the Bonneville and Lahontan Basins, not only would our knowledge of displacement be increased, but an important contribution might be made to the more difficult subject of the condition of the interior of the earth.

OFFICE-WORK.

The writer has continued the preparation of his long-delayed memoir on Lake Bonneville, and has specially arranged a chapter of it for publication in this volume. A portion of his time has likewise been occupied with the discussion of the influence of terrestrial rotation on the character of river valleys, and with the elaboration of a plan for the subject bibliography of geologic literature.

Mr. Russell has continued the preparation of his report on Lake Lahontan, and has prepared for the present volume an essay on the

existing glaciers of the Sierra Nevada. He has also continued his investigations on the rate of precipitation of fine sediment from natural waters. For the purpose of verifying certain conclusions in regard to rivers and rotation, he visited Long Island in the latter part of March and spent a number of days in the study of its hydrographic system.

Mr. Johnson has been occupied with the elaboration of his field-notes and with the preparation of illustrations for Mr. Russell's papers and my own. In the latter work we have received assistance also at various times from Mr. Ricksecker of the Yellowstone division.

The study of the Quaternary shells of the Great Basin, undertaken by Mr. R. Ellsworth Call, has been completed; and his report, which treats also of the recent fresh-water shells of the same district, has been submitted. It will shortly be offered for publication as a bulletin.

The discussion of the problem of the chemical history of thinolitic tufa which had been undertaken by Prof. George J. Brush was afterward, at his request, assumed by Prof. Edward S. Dana, who has made important progress and is expected to submit a report at an early day.

The division is under obligation to the chemical division, which has reported numerous analyses of waters and minerals, and has otherwise cordially co-operated.

Mr. Henry I. Van Hoesen has rendered acceptable aid to Mr. Russell by performing the computations necessary to reduce a large number of analyses of mineral waters to a common standard.

I remain, with great respect, your obedient servant,

G. K. GILBERT,
Geologist.

Hon. J. W. POWELL,
Director, U. S. Geological Survey, Washington, D. C.

REPORT OF MR. W J M'GEE.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 22, 1884.

SIR: I have the honor to submit the following report of work performed during the year ended June 30, 1884:

The major portion of the year was spent in office-work; but field-work was incidentally accomplished.

OFFICE-WORK.

In accordance with your oral instructions of July 7, 1883, I undertook the compilation of a general geologic map of the United States designed (1) to illustrate a system of geologic cartography devised by yourself,

and (2) to exhibit the distribution of American formations as determined by the latest investigations. As an essential preliminary thereto I immediately commenced a study of American geologic publications, both cartographic and textual; and the record of results of such study naturally assumed a form readily expansible into a thesaurus of American formations. Then came your oral instructions of November 20 to prepare a hand-colored copy of the contemplated map at the earliest possible date, and your employment of Prof. C. H. Hitchcock, of Dartmouth College, to assist in its preparation. These instructions, your oral instructions of January 20, 1884, to recompile the data in a form suitable for publication, and your final oral instructions of March 1, to invite the co-operation of the state geologists of New York, Pennsylvania, and New Jersey in constructing a local geologic map including these states, led to material modification of previous plans; and further modification grew out of the necessity for editorial work on a manuscript map and accompanying text employed in the compilation of the general map. Thus my work became differentiated into distinct lines, and has been expended upon (1) a manuscript geologic map, (2) a general geologic map designed for immediate publication, (3) a local geologic map, (4) a thesaurus of American formations, and (5) a sketch of the geology of Texas, Indian Territory, Arkansas, and Louisiana.

THE MANUSCRIPT MAP.

This is a hand-colored geologic map of the United States, on the double-atlas-sheet base prepared under the direction of Henry Gannett, chief geographer United States Geological Survey. Its scale is 1: 7,115,000 (112.3 miles = 1 inch). It is colored by groups, the following being the divisions represented, viz: 1, Quaternary (including recent deposits); 2, Plio-Miocene; 3, Oligo-Ecene; 4, Cretaceous (including Laramie); 5, Jurasso-Triassic; 6, Permo-Carboniferous; 7, Devonian; 8, Silurian; 9, Cambrian (from summit of Potsdam to summit of Huronian); 10, Archean; and, 11, Volcanic.

In the compilation of this map use was made (1) of all previously published maps, whether original or compiled, (2) of textual descriptions of terranes and notes of outcrops, and (3) of manuscript material; and in some cases the geologic structure of unsurveyed areas, was inferred from that of contiguous surveyed areas. Accordingly the colors extend over nearly the entire territory of the United States; but the coloration is to an extent hypothetic.

The map was completed in January. Its satisfactory execution and early completion were largely due to Professor Hitchcock's energy, his experience and skill in geologic cartography, his extended personal knowledge of American terranes, and his familiarity with American geologic literature.

THE GENERAL MAP.

The data employed in the construction of this map were (1) published maps based on original investigation, and (2) manuscript maps, also based on original work, prepared for the Survey by state geologists and others. The more recently published maps were generally given precedence; no attempt was ever made to project boundaries or extend colors beyond the areas delineated on the original maps, and though a definite taxonomic scheme was adopted, the original classification was modified as little as possible; and unmapped regions as well as regions in which the age of the rocks is in serious dispute were left blank. Accordingly the completed map may be regarded as authentic in all its parts,—its reliability depending simply upon the accuracy of the originals employed.

The taxonomic scheme adopted, with explanatory remarks, is appended:

Era or system.	Period or group.	Color.	Letter-symbol.	Remarks.
Cenozoic	Quaternary	Gray	Q	Includes recent deposits. Represented only where known to exist and where subjacent rocks are unknown.
	Neocene	Light yellow	N	Pliocene and Miocene.
	Eocene	Dark yellow	E	Including Oligocene.
Mesozoic	Cretaceous	Light green	K	Including Laramie.
	Jurasso-Triassic	Dark green	T	Jurassic and Triassic.
Paleozoic	Carboniferous	Blue	P	Permian, Coal Measures and Sub-Carboniferous.
	Devonian	Dark purple	D	
	Silurian	Light purple	S	Upper Silurian and Lower Silurian.
	Cambrian	Deep purple	C	All rocks between summit of Potsdam and summit of Huronian.
Azoic	Archean	Brown	A	All non-volcanic crystallines.
	Volcanic	Red	V	All eruptives.

NOTE.—Through error on the part of the lithographer and oversight on the part of the proof-reviser, the colors on the accompanying impression of the map depart slightly from this scheme.

The following published maps were employed in the states and territories here enumerated:

States.	Maps and authors.
Arizona	"Geological Map of the Western Part of the Plateau Province." Dutton. Acc. Monog. II, U. S. Geol. Surv., 1882.
	"Geological Atlas." Wheeler. Sheets 66, 75, 76, 83.
Colorado	"General Geologic Map of the area explored and mapped by Dr. F. V. Hayden." Acc. 12th Ann. Rep. U. S. Geol. and Geog. Surv. Ter., 1883.
Connecticut	"Geological Map of the United States and Territories," 1882. Hitchcock. (Though this map is a compilation, the cartography in New England is largely based on original work by its author. It was accordingly followed in the Eastern States.)
Dakota	Hayden's "General Geologic Map," *op. cit.*
	"Geological Map of the Black Hills of Dakota." Newton. Acc. Newton and Jenney's Rep. Geol. and Res. Black Hills, 1880.
	"General Map of the Terminal Moraine," etc. Chamberlin. In 3d Ann. Rep. U. S. Geol. Surv., 1883.
Florida	"Geological Map of Florida." Smith. *Am. Jour. Sci.*, XXI, 1881, 305.
Idaho	Hayden's "General Geologic Map," *op. cit.*
Illinois	"Geological Map of the State of Illinois," 1875. Worthen.
Kansas	Geologic map in 1st biennial rep. St. Board Ag. Kans., vol. VI, 1878, 47. Mudge.
Kentucky	Geologic map of Kentucky. Proctor.
Maine	Hitchcock's "Geological Map," *op. cit.*
Maryland (in part)	"Geological Illustrations." Tyson. Acc. 1st rep. St. Agric. Chemist, 1860.
Massachusetts	Hitchcock's "Geological Map," *op. cit.*
Michigan	"Geological Map of the Lower Peninsula." Rominger. Acc. Geol. Surv. Mich., III, 1876.
	"Geological Map of the Lake Superior Basin." Irving. In 3d Ann. Rep. U. S. Geol. Surv., 1883.
Mississippi	"Geological Map of Mississippi." Hilgard. Acc. Rep. Geol. and Agric. Miss., 1860.
Missouri (in part)	"Campbell's Geological Map of Missouri." In New Atlas of Mo., 1873.
Montana	Hayden's "General Geologic Map," *op. cit.*
Nebraska	Hayden's "General Geologic Map," *op. cit.* Map acc. Hayden's Fin. Rep. U. S. Geol. Surv. Neb., 1872.
Nevada	King's Geol. and Topog. Atlas 40th Par., 1876.
	Wheeler's "Geological Atlas," *op. cit.*, sheets 58, 66.
New Hampshire	Hitchcock's "Geological Map," *op. cit.*
New Jersey	"Geological Map of New Jersey." Cook. Acc. Ann. Rep. Geol. Surv. N. J. for 1882.
New Mexico	Hayden's "General Geologic Map," *op. cit.*
	Stevenson's geologic maps. Acc. Rep. U. S. Geol. Surv. W. 100th Merid., vol. III, Supplement—Geology, 1881.
	Wheeler's "Geological Atlas," *op. cit.*, sheets 76, 83.
New York (in part)	"A Geological Map of Richmond Co., N. Y." (Staten Island). Britton. In Ann. N. Y. Acad. Sci., II, 1881.
North Carolina (in part)	"Geological Map of North Carolina." Kerr. Acc. Rep. Geol. Surv. N. C., vol. I, 1875.
Ohio	"Geological Atlas of the State of Ohio." Newberry *et al.*, 1879.
Rhode Island	Hitchcock's "Geological Map," *op. cit.*
South Carolina (in part)	"Geological Map of South Carolina." Tuomey. 1845. Acc. titleless rep. on geol. S. C.
Tennessee	Map acc. "Geology of Tennessee." Safford. 1869.
Utah	Hayden's "General Geologic Map," *op. cit.*
	Dutton's "Geological Map," &c., *op. cit.*
	King's Geol. and Topog. Atlas, *op. cit.*
	Wheeler's "Geological Atlas," sheets 50, 58, 59.
	Powell's "Atlas." Acc. Rep. Geol. Uinta Mountains, 1876.
Virginia (in part)	"Hotchkiss' Geological Map of Virginia and West Virginia." Rogers.
Washington	"Geological Sketch Map of British Columbia." G. M. Dawson. *Geol. Mag.*, II, VIII, 1881, 160.
West Virginia	"Hotchkiss' Geological Map," *op. cit.*
Wisconsin	Irving's "Geological Map of the Lake Superior Basin," *op. cit.*
	"General Geological Map of Wisconsin." Chamberlin. In Atlas Geol. Surv. Wis., 1883.
Wyoming	Hayden's "General Geologic Map," *op. cit.*

The manuscript maps made use of are enumerated in the accompanying list; and the indebtedness of the Survey to their respective authors is here expressed. The material thus accumulated will be permanently preserved.

States.	Authors.
Alabama	Dr. Eugene A. Smith, state geologist.
Arkansas	Dr. R. H. Loughridge, special agent Tenth Census.
Delaware	Prof. J. Peter Lesley, director 2d Geol. Surv., Pa.
	Prof. Angelo Heilprin.
Georgia	Dr. R. H. Loughridge, [ex-] assistant state geologist.
	Mr. A R. McCutchen, [ex-] assistant state geologist.
Indiana	Prof. John Collett, state geologist.
Indian Territory	Dr. R. H. Loughridge, special agent Tenth Census.
Iowa	W J McGee.[3]
Louisiana	Dr. R. H. Loughridge, special agent Tenth Census.
Maryland (in part)	Prof. Angelo Heilprin.
Minnesota	Prof. N. H. Winchell, director Geol. and Nat. Hist. Surv., Minn.
Missouri (in part)	Prof. G. C. Broadhead, [ex-] state geologist.
New York (in part)	Prof. James Hall, state paleontologist.
	Prof. George H. Cook, state geologist of New Jersey.[4]
North Carolina (in part)	Prof. W. C. Kerr, [ex-] state geologist.
	Prof. Angelo Heilprin.
Pennsylvania	Prof. J. Peter Lesley, director 2d Geol. Surv., Pa.
South Carolina (in part)	Prof. Angelo Heilprin.
Texas	Dr. R. H. Loughridge, special agent Tenth Census.
Virginia (in part)	Prof. Angelo Heilprin.

[3] Prepared under the auspices of the Tenth Census.
[4] Long Island was colored by Professor Cook.

Much of the western portion of the United States remains unexplored geologically; repeated efforts were made to gain access to the unpublished material of the now suspended geologic survey of California, and to establish correspondence with the state geologist of Oregon, but without success; the maps prepared by the earliest western explorers can seldom be accurately co-ordinated with those recently published, either geographically or geologically, and it became necessary to leave the following states and territories either partially or wholly uncolored: Arizona, California, Idaho, Montana, Nevada, New Mexico, Oregon, Texas, Utah, Washington.

The courtesy of Dr. A. R. C. Selwyn and Dr. G. M. Dawson in communicating a tracing of the prospective geologic map of the portion of British territory contiguous to the United States is gratefully acknowledged. Unfortunately this tracing arrived too late for use.

Work on the sheet was completed in April. A hand-colored copy has since been prepared for immediate use, and the original is ready for the engraver. When printed it will form a double atlas-sheet of the standard dimensions adopted by the Survey. Its scale is 1 : 7,115,000.

An explanatory memoir embodying (1) a synopsis and discussion of the classification adopted; (2) a list of authorities followed (together with a statement of all taxonomic modifications and an enumeration of all cartographic alterations made in (*a*) uniting discrepant original sheets, (*b*) unifying the scale, and (*c*) adjusting geology to drainage); and (3) a bibliography, including full titles of maps and memoirs referred to, has been prepared. It awaits revision with the final proof of the map. It will occupy 40 or 50 pages.

THE LOCAL MAP.

This map is designed (1) to illustrate the applicability of your cartographic system to the representation of minor geologic divisions on large-scale maps, and (2) to finally eliminate the existing taxonomic discrepancies between certain contiguous fields alike classic in American geology. The region included embraces New York, Pennsylvania, and New Jersey. The map will be colored by formations; and since the scale is 1:380,160 (6 miles = 1 inch), all narrow zones shown on the various large-scale original maps may be satisfactorily reproduced.

Pending the cartographic work proper, a convention of the chief geologists officially employed in the three states—Professors James Hall, J. Peter Lesley, and George H. Cook—was arranged for the double purpose of securing their co-operation in the work and of devising a uniform stratigraphic scheme equally applicable in the several states. Such convention was held in this office on April 14, 1884; and, through the courtesy and liberality of the gentlemen participating, its purposes were successfully accomplished.

A base-map of the region was rapidly drawn under the direction of the chief geographer, and is now in the hands of the photo-lithographer. The geologic data have been assembled and systematized, and can be speedily transferred to the base on its completion; but since the map must undergo revision at the hands of each geologist co-operating in its preparation, some weeks must elapse before it can be submitted.

The indebtedness of the Survey and my own personal obligation to Professors Hall, Lesley, and Cook, cannot be too warmly expressed.

THE THESAURUS OF AMERICAN FORMATIONS.

The material derivable from inspection of the literature of classification and nomenclature of geologic formations falls naturally into four categories, relating respectively (1) to the phenomena classified, (2) to the method of classification, (3) to the terms employed in the classification, and (4) to the bibliothecal place of classification. Accordingly, I early contemplated and now have under way the elaboration of four treatises corresponding to these categories. They are as follow:

1. *A compend of American formations*, in which the various rock-masses specifically discriminated and authoritatively recognized shall be grouped in natural sequence in both vertical and horizontal directions. The grouping in the vertical plane may be effected in a table divisible into pages. The grouping in the horizontal plane is geologic cartography; and the general geologic map already prepared thus constitutes a definite but subordinate member of the prospective thesaurus. Obviously the contemplated grouping of formations can be finally accomplished only after the sum of information concerning the formations has been collated and digested; and accordingly little progress has been made in this direction beyond the compilation of a first copy of the map.

2. *A conspectus of classification of American formations*, in which shall be assembled not only the diverse tabular arrangements of rock-mass designations proposed by different geologists, but also tables compiled from the writings of those geologists who have failed to formulate their conceptions of stratigraphic and taxonomic relation. (Only systematic schemes have been transcribed or compiled. Purely descriptive sections are neglected.) The work—particularly that of compiling tables from vague geologic writings—has proven tedious; but 150 tables, derived from about half of the official and a small portion of the unofficial geologic literature of the United States, have been accumulated.

3. *A dictionary of American formation names*, in which the origin, significance, synonymy, present status, etc., of each term ever applied to an American rock-mass, together with full bibliothecal references, shall be recorded. The data expansible into such dictionary are recorded on cards; but the final digestion of the data cannot, manifestly, be accomplished until the greater part of our geologic literature has been carefully scanned. About 1,000 cards have been assembled, and partial digestion has been effected in some cases.

4. *A bibliography of American formations*, in which the titles abbreviated in compend[5], conspectus, and dictionary shall be systematically arranged and recorded *in extenso*. The titles of a considerable portion of the publications already scanned have been transcribed on suitable cards. The method of recording material pertaining to this division of the thesaurus, as well as to the others, is such that any arrangement of entries found desirable at any time in the future may be adopted.

These categories of information may be separately collated and published; but they should be ultimately combined under some such general title as that applied above.

So full statement of methods and purposes, in advance of commensurate results, is made, partly in the hope of eliciting valuable criticism and suggestion and partly to facilitate utilization of the material already accumulated in case of my transference to other duty.

THE GEOLOGIC SKETCH OF TEXAS, ETC.

In collating material for the general map, a dearth of data employable in delineating the formations of Texas, Indian Territory, Arkansas, and Louisiana was discovered; and at my solicitation Dr. R. H. Loughridge, then special agent of the Tenth Census, commenced the construction of a geologic map exhibiting the results of his extended observations in these States. Development of the original plan led to the preparation of explanatory notes; and further development of plan, induced by the importance of the subject, led to the amplification of the notes into a connected sketch, the incorporation in map and text of the results of previous investigation in the same field, and the compilation of a geologic bibliography of the region. Thus the map and sketch

[5]The titles recorded in the explana tory memoir accompanying the general map are not abbreviated.

are designed to embody the sum of present knowledge of the geology of the four states, conveniently colligated. Unfortunately Dr. Loughridge's employment by the geologic survey of Kentucky, and his consequent departure from this city, prevented the consummation of his design; and his preliminary manuscript was left in my hands for editorial revision and elaboration.

Considerable labor has been expended in this work. The map is now ready for the engraver, and the text approaches completion.

FIELD-WORK.

Agreeably to your oral instructions of July 15, 1883, I have devoted intervals of leisure to study of the superficial deposits of the District of Columbia and contiguous territory.

I early discovered that such study involved the investigation of (1) the subjacent Mesozoic and Cenozoic deposits, and (2) the Quaternary (?) terraces of the region; and that the latter phase of the investigation involved the construction of an accurate topographic map of the entire area examined. In response to my representation to that effect, Mr. Sumner H. Bodfish, topographer United States Geological Survey, was detailed to survey and map the region. The contemplated map is a rectangle, including an area 22½ by 26 miles (extending from 76° 50′ to 77° 19′ in longitude and from 38° 46′ to 39° 05′ in latitude), with Washington in its center. The scale of the field-sheets is 1:31,680 (one-half mile = 1 inch). Special care has been exercised throughout in the determination of the vertical element.

Progress on this map is confined to the compilation of existing data and the original survey of some 56 square miles in Fairfax County, Virginia.

The geologic work practically performed includes (1) a reconnaissance of the entire region; (2) the discrimination of the various superficial deposits of the District of Columbia so far as this can be effected without better maps; (3) the identification of the principal terraces of the region; (4) a careful examination (without instrumental measurement) of the profiles of the Potomac River and its tributaries; (5) a preliminary study of the behavior of these streams during freshets, and (6) oversight of the nascent topographic map. The aggregate length of routes traversed, outside the city, is only about 500 miles; but since most routes were traversed repeatedly, the total distance traveled in the prosecution of the work exceeds 2,000 miles. Little further progress can be advantageously made pending the completion of the topographic map.

I am, sir, very respectfully, your obedient servant,

W J McGEE,
Assistant Geologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF CAPT. C. E. DUTTON.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1884.

SIR: Herewith I have the honor to submit my report of the geological work performed under my direction during the fiscal year ended June 30, 1884.

Under your instruction Mr. Gilbert Thompson extended the topographic surveys in northern California in the vicinity of Mount Shasta, and during the winter completed a map of that volcano and of the adjoining country. The drawing of this map having been completed in a highly satisfactory manner during the past winter, the section of country which it portrays is now ready for geological study.

The investigation of the great chain of volcanoes constituting the Cascade Range in California, Oregon, and Washington Territory, having devolved upon me, I directed my assistant, Mr. J. S. Diller, to make a preliminary reconnaissance of that portion of it which lies between the head of the Sacramento Valley and the Columbia River. Nothing further was contemplated by this reconnaissance than ascertaining the salient features of the country in its vicinity and selecting such subordinate tracts as might be typical of the larger and more general features of the range, for the purpose of future study in detail. Mr. Diller organized his party, with the assistance of Mr. Gilbert Thompson, at Red Bluff, in the northern part of the Sacramento Valley, and successively visited Lassen's Peak and Mount Shasta. He was accompanied by Ensign E. E. Hayden, United States Navy. Mr. Diller was instructed to observe carefully the petrographic characters of the eruptive rocks and to collect specimens of them; to note carefully the formations of fragmental volcanic products and their modes of accumulation; to obtain such information as was practicable concerning the relative ages of the various eruptive masses and their relations to each other. He was also instructed to look carefully for exposures of sedimentary and metamorphic formations among the volcanic and in the immediate vicinity of the latter. His attention was also directed to any noteworthy and instructive structural features, such as faults and displacements of great extent, which might throw light upon the question as to whether the range owed its development wholly to the accumulation of extravasated matter or in part to a general uplifting of the great platform on which the volcanic piles now stand. In the same connection he was advised to watch the features and study the characteristics of the drainage system and the relations of the rivers to the structural features of the country through which they run.

Mr. Diller's journey was a long one, and comprised far too large a field to enable him to carry out in detail and upon a comprehensive plan a

systematic inquiry into the subjects suggested for his observation. He accomplished, however, a great deal, though often working under adverse circumstances. After visiting Mount Shasta he proceeded to the eastern base of the range, gradually working his way to Fort Klamath. From that post he visited the more striking volcanic piles in its vicinity, and also the very interesting locality known in the vicinity as Crater Lake.

He achieved, however, the main object of his reconnaissance, for he disclosed how this grand theater of volcanic activity, now extinct, may best be studied in the future.

During the past winter Mr. Diller has been studying diligently the characters and constitution of the lavas he brought with him, and finds many instructive varieties among them. These will form a part of a large series of studies, and ultimately find their place in the discussion of future results and future collections. At present it is practicable only to "report progress."

In conformity with your advice, I did not deem it best to engage in active field service last summer, but remained in Washington to write a memoir setting forth the results of some extended observations of the volcanoes of the Hawaiian Islands, which memoir has been published as a contribution to the Fourth Annual Report of the Director of the Geological Survey. This investigation was undertaken with a view of becoming familiar with a great volcano in a state of full activity, and for purposes of comparison with the volcanic phenomena of the western portion of our own country.

Very respectfully, sir, etc.,

C. E. DUTTON,
Captain of Ordnance.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. S. F. EMMONS.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE ROCKY MOUNTAINS,
Washington, D. C., June 30, 1884.

SIR: I have the honor to submit herewith a report of operations in the Division of the Rocky Mountains (Mining Geology) under my charge for the year ending June 30, 1884.

In the early part of the year the scientific corps of this division lost the services of Mr. Ernest Jacob, who had been attached to it since the inauguration of the Survey; he had previously been obliged to ask for leave of absence, as noted in former reports, on account of ill health, brought about by too close application to field-work at the high altitudes of the Leadville and Ten-Mile districts, but had reported again for serv-

ice and commenced field-work at Silver Cliff. After a short trial he found that it would be impossible for him to continue this class of work, and he therefore tendered his resignation, to take effect when he should have completed the writing up of his notes. To a great natural ability in deciphering the problems of stratigraphical geology, Mr. Jacob united a conscientious and untiring spirit of devotion to the work upon which he was engaged, and in the four years of his connection with the Survey had acquired such familiarity with the complicated investigations which are required in the work of mining geology that it will be difficult to fill his place.

At the commencement of the year Mr. L. G. Eakins was appointed geologic assistant, and his services during the year, both in the field and in the laboratory, have been highly satisfactory.

The field-work planned at the commencement of the year was, first, the geological investigation of the Silver Cliff mining region; second, the preparation of a topographical map of the Gunnison region; and, third, a topographical and geological survey of a region, about 30 miles square, having Denver as a center, with special reference to the artesian water and coal basins included therein.

Silver Cliff region.—An excellent topographical map of the Silver Cliff region had already been prepared by Mr. Karl and his assistants during the summer of 1882. Geological work was commenced on the 1st of July, and continued till near the end of September, the field party consisting of Messrs. Cross, Chaplin, and Eakins, I myself taking part in the work during the greater part of the time.

While the prosecution of the work has demanded less severe physical labor than was necessary in the districts hitherto examined, it has also proved less fruitful in economic and scientific results. The time of our visit was also one of extreme depression in its mining interests, one of those that seem to form an essential epoch in the history of most mining districts, and a large proportion of the mines were, for the time being, abandoned and inaccessible; hence the study of ore deposits in the field was necessarily limited, and this, together with the extremely decomposed nature of the eruptive rocks of which the region is almost exclusively composed, has necessitated a chemical and a microscopical investigation relatively much longer before conclusions sufficiently definite for publication can be arrived at. These had not been entirely completed at the time field-work for the present summer was resumed, and it will require another short visit to the region before the geological colors can be definitely outlined upon the map.

Gunnison region.—The area under survey in this region comprises the southern portion of the Elk Mountains, and the valuable coal fields on their southern and western flanks tributary to the towns of Crested Butte and Gunnison. Owing to the extremely rugged character of its mountains, and the great complexity of its geological structure, its investigation will necessarily be very long and laborious, but it is hoped the

results will prove of corresponding value both to geology in general and to the study of vein phenomena in particular. It was judged by you that the detailed maps of a portion of this area already in the possession of the Survey would be sufficiently accurate for our purpose. It was only necessary to make a new map of the remaining portion. For this purpose, Mr. Karl, with a complete corps of assistants, took the field at the very commencement of the fiscal year, and in spite of natural obstacles had pushed his work so vigorously that field-work would probably have been completed by October 1, when it might be expected that he would be cut off by snows in the high mountain regions. About the middle of September, under orders received from the Secretary of the Interior, he was detached for service under the Land Office for verifying the surveys of the Maxwell land grant, and all further work in this region was abandoned until another year. Until his maps are completed it would be unwise to commence any elaborate geological investigations, as the work done would need to be gone over again map in hand.

Denver region.—In the high mountain regions of Colorado, in which a great part of our investigations are made, the season when the rocks are sufficiently free from snow for rapid and satisfactory work is so short, that it seemed to me wise that surveys should be simultaneously undertaken at lower altitudes, which could be prosecuted during the spring and autumn months. It was partly with this view that the examination of the plain country around Denver was undertaken. Already a map had been compiled from Land Office and railroad surveys of the area, something over 30 miles square, which it was intended to study geologically. A comparatively short season of topographical field-work was required to correlate, verify, and supplement the data thus obtained and make a complete map of the region of sufficient accuracy for our purposes. Ample time for this, it was estimated, would have been had between the completion of the field-work in Gunnison and the advent of winter. The diversion of our topographical corps to Land Office work, which occupied them until December, has, however, prevented the carrying out of this original plan, according to which the map would have been platted during the winter months and be now in the hands of the geologists. I had been anxious to have this map for the purpose of completing investigations which have been undertaken by us in regard to the water supply of Denver and vicinity, which may be counted on from artesian wells, of which over forty have been sunk with most favorable results as regards both quantity and quality of water obtained during the past year. The practical bearing of this study is not confined to Denver, but extends to the whole region of the great plains. While the existence of a synclinal basin has long been known to us from the hasty observations one makes in simply passing over the country, accurate and reliable maps and profiles are an indispensable basis for the observations which shall determine the true source

of the water supply, the amount and quality that may be expected from different geological horizons, and the most favorable points for sinking artesian wells; it is in large degree owing to the want of this accurate preliminary knowledge that the money already appropriated by Congress and spent in sinking artesian wells upon the plains of Colorado has been so barren of practical and definite results.

About the middle of May Mr. Karl took the field again with his topographical corps to complete the field-work upon this map, and Messrs. Cross and Eakins have accompanied his parties to make preliminary studies upon the geology of the region. As his notes, however, cannot be platted until after the close of the field season, it will necessarily be impossible to complete the work before the close of another year. It is my intention, when this field-work is completed, to send a combined topographical and geological party to the Gunnison region, of which the one branch shall complete the map commenced last summer and make a more detailed map on a large scale of the region immediately adjoining the already opened coal mines, while the geologists will gather what material they can for laboratory and microscopic investigation; the geological work, without completed maps, can at best be but a reconnaissance.

Of the monographs mentioned in my last report, the studies for those of the Ten-Mile District and of the Golden Mesas are practically completed. The former only awaits final writing to be ready for the printer. The latter is in great part written, but it has been found that certain portions could not be finally treated until the result of the investigations over the whole area of the Denver map should be known, and it has hence been judged wiser to postpone its publication for the present, and incorporate it in the final monograph on the whole area.

For the Silver Cliff monograph, as above mentioned, some additional field-work is still required before the material gathered can be put in shape for publication.

In addition to the regular studies in connection with the various monographs above mentioned, mineralogical and chemical investigations have been made in the laboratory at Denver by Messrs. Hillebrand and Cross on various interesting minerals from Colorado and adjacent Territories hitherto unknown there, many extremely rare in any country, some of which have been known before only in isolated localities outside of the United States and one or more of which were entirely unknown to science.

Some of these have already been described in the pages of the American Journal of Science, viz., the group of cryolite minerals from Pike's Peak, including cryolite, pactinolite, thomsenolite, gearksutite, prosopite, probably ralstonite, and a new fluoride in which two-thirds of the sodium is replaced by potassium, sanidine with a peculiar cleavage, and topaz from the rhyolite of Chalk Mountain in Summit County, the first time, so far

as known, that the latter mineral has been found in so recent a rock, its habitat being hitherto supposed to be confined to the crystalline or earlier eruptive rocks; besides these, the following metallic minerals: hübnerite, cosalite, cobaltiferous and nickeliferous löllingite, and a new bismuth mineral.

Owing to the absence of both Mr. King and Mr. Becker, the responsibility for the volume of the census report on precious metals, the materials for which were gathered under our supervision, has fallen upon me, and no inconsiderable portion of my time has been occupied in necessary revision and proof-correcting. For this and other reasons I have not made as rapid progress in the preparation of the manuscript of the various monographs of this division for the press as I could have desired.

Very respectfully, your obedient servant,

S. F. EMMONS,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. G. F. BECKER.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF THE PACIFIC,
San Francisco, Cal., July 1, 1884.

SIR: I have the honor to present the following report of my operations during the year ended June 30, 1884.

At the date of my last annual report Mr. John D. Hoffmann had begun the topography of the difficult region of New Idria. The field-work was not completed until February 1, but a few days later Mr. Hoffmann was able to place in my hands a map which I have since found to be of photographic accuracy. He then proceeded to Clear Lake to make some additions to the map of Sulphur Bank, and at the conclusion of that work was summoned to Washington to labors unconnected with my division. Mr. Hoffmann's assistant, Mr. J. Ahern, with one rodman, began a map of small area including the Great Eastern Quicksilver Mine, near Gurneville. in May, the field-work for which is now almost completed.

At the beginning of the fiscal year I was employed in studying the geology of the Sulphur Bank. I soon found it impossible to correlate the phenomena there observed with the structure and geological history of the surrounding region, without the examination of a comparatively large area. I contracted with Mr. C. F. Hoffmann to compile a brush-shaded topographical map on a scale of 1 mile = 1 inch, from existing material, upon which I laid down the geology of an area of 225

square miles, including the lake. I also made a sufficient number of soundings to enable me to lay down the subaqueous contours of the basin.

In February I undertook the geology of the quicksilver mining region of Knoxville, of which Mr. Hoffmann had prepared a map during the preceding fiscal year. Mr. W. H. Turner, my geological assistant, had already done two months' field-work in this neighborhood, greatly facilitating my labors and enabling me to complete the region about the middle of March. In connection with this district, we made reconnaissances extending as far as Mount Saint Helena on one side and Cache Creek on the other.

Shortly after the completion of the Knoxville area Mr. Turner proceeded to Tres Pinos to make a general examination of the surrounding country. Here I followed him about the middle of April and traveled with a camping outfit by short stages to New Idria by the way of Panoche Valley, making lithological and paleontological collections, and studying a number of abandoned quicksilver mining localities. The study of New Idria, including reconnaissances extending from the San Joaquin Valley to the Rio San Benito, occupied us until the middle of June, though it could have been finished in a shorter time, but for a succession of unseasonable storms of great severity. I then returned slowly through the San Benito Valley to Tres Pinos, making important paleontological collections on the way, and reached San Francisco June 21. More or less field-work has been done during every month of this fiscal year.

The districts examined suggest many important structural, lithological, paleontological, and chemical questions, and if these or only a part of them can be satisfactorily settled a considerable advance will have been made in the correlation of the general geology of the coast ranges and the occurrence of quicksilver deposits, as well as important additions to what is known of the nature of these deposits. A considerable part of the office-work, connected with the districts mentioned, remains to be done, however, and a reasonable hope is entertained that further field-work to be prosecuted during the coming fiscal year will throw additional light upon that already accomplished. Any statement of the results reached would therefore be premature.

At my request, Dr. C. A. White was ordered to this coast, during the last month of the fiscal year, for a stay of a few months, during which he hopes to obtain the information necessary for the determination of the considerable collection of new fossils and new associations which I have gathered.

Dr. Melville has been busily engaged throughout the year in analyzing rocks, waters, and minerals from the quicksilver districts, and in investigating some of the chemical relations of quicksilver. In this last inquiry in which I have partaken, a large number of hitherto unknown reactions have been established. It was hoped that a paper setting

forth the results of this investigation would have been ready before this time, but the press of other duties has prevented.

Mr. J. S. Curtis finished his monograph on the Eureka silver lead deposits in the autumn, and after a revision of the entire work with me, and a final visit to the district, reported at Washington with the manuscript in January. The volume, of about 200 pages, is now entirely in type and the proof corrected. Mr. Curtis is at present engaged in preparing a model of the mines for the National Museum.

Very respectfully, your obedient servant,

G. F. BECKER,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S Geological Survey, Washington, D. C.

REPORT OF PROF. O. C. MARSH.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF PALEONTOLOGY,
New Haven, Conn., July 1, 1884.

SIR: I have the honor to submit the following report of progress in this division during the past year.

In acordance with your letter of general instructions, dated July 1, 1882, I have continued the systematic work of collecting fossils in the West, especially in the regions that promised to yield specimens needed to complete the investigations already commenced.

One party was at work in the Tertiary deposits of Oregon during part of the year, and made important collections of fossil mammals from the Miocene.

Two parties spent the season in exploring the Jurassic beds of Wyoming, and met with good success, bringing together large collections of Dinosaurian reptiles and Jurassic mammals, among which were not a few new to science.

Another party continued the investigations of the Jurassic deposits near the Arkansas River, in southern Colorado, where discoveries of importance were made.

During the present season, one party has been engaged in exploring the Pliocene deposits of Kansas and Nebraska, where very large collections of fossil mammals have been secured.

In the Jurassic of Wyoming three parties are now at work, with every prospect of success, while in southern Colorado work in the same horizon has been carried on systematically, and important results have been obtained.

The memoirs in preparation have made good progress during the past year. The volume on the *Dinocerata* is now in press, and, it is expected, will soon be published.

The monograph on the *Sauropoda*, the huge Jurassic reptiles found in the Rocky Mountains, also approaches completion, and the plates which illustrate it are nearly all printed.

Satisfactory progress has been made on the volume relating to the *Stegosauria*, and, also, on the others now in preparation.

Very respectfully, your obedient servant,

O. C. MARSH,
Paleontologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF DR. C. A. WHITE.

UNITED STATES GEOLOGICAL SURVEY,
San Francisco, Cal., July 1, 1884.

SIR: I have the honor to submit the following account of my work during the fiscal year ended June 30, 1884.

On the 2d of July, 1883, I left Washington and proceeded *via* Helena to Fort Benton, Montana. At Saint Paul, Minn., Mr. John B. Marcou reported to me as assistant, and at Glendive, Mont., I increased my party by the addition of Mr. Melvin S. Wade.

After a slight delay at Fort Benton for outfitting, I crossed the Missouri and traveled southward to Judith River, passing near Highwood and Moccasin Mountains, and then turned northward to the point where that river empties into the Missouri. Here, as also throughout my field of operations, I gave especial attention to the Laramie Group, investigating its relation to the underlying Cretaceous and making collections of fossils. Returning by the same route to Fort Benton, I made an excursion with similar errand to the Bear Paw Mountains, and a second excursion to the Great Falls of the Missouri. My party was then joined by Mr. Lester F. Ward, and he continued with us to Bismarck, Dak., the journey being made in a row-boat on the Missouri River. By this voyage a distance of 1,050 miles was traversed in thirty days, and I was enabled to examine many hundred miles of exposure of strata of the Laramie Group, far more than I could have accomplished by any other method. From Bismarck Mr. Wade returned to Glendive, while Mr. Marcou and I continued field-work in southwest Dakota and the adjacent parts of Iowa and Nebraska.

Upon our arrival at Washington, Mr. Marcou began the arrangement and labeling of the large number of type specimens of Mesozoic and Cenozoic species, which have been described in the various reports published by the United States Government, and now belong to the Survey and to the National Museum. This work, so far as the type specimens are concerned, is now practically finished, and Mr. Marcou

is now engaged in doing a similar work for the other Mesozoic and Cenozoic invertebrate fossils of the Survey and the Museum, and preparing them for installation in the Museum cases.

Mr. Lawrence C. Johnson, who has been collecting fossils for the Survey from the Cretaceous and Tertiary rocks of the Gulf States, was ordered by you to return from the field last January and report to me. He has since that time been engaged in unpacking his large collections and labeling them as to locality and geological position. He has also drawn a detailed section of the strata, showing his view of their proper correlation.

Besides the work just referred to, much routine work has been done upon the collections belonging to the Survey, and much more upon those belonging to the National Museum.

Since my return from the field in October last, my own time has been spent in the study of the various questions which have arisen during the progress of the work of my division. I have made some special studies of Mesozoic fossils, the results of which are now in the printer's hands, to form Bulletin No. 4 of the publications of the Survey. The following are the titles of the separate papers constituting that Bulletin: "Description of certain aberrant forms of the Chamidæ from the Cretaceous rocks of Texas"; "On a small collection of Mesozoic fossils obtained in Alaska by Mr. W. H. Dall, of the United States Coast Survey"; "On the Nautiloid, genus Enclimatoceras Hyatt, and a description of the type species."

By your permission I have also published in the February number of the American Journal of Science for 1884 an article entitled "Glacial Drift in Montana and Dakota," as one of the results of my last season's field-work.

At the request of Mr. G. F. Becker I have recently undertaken a paleontological investigation designed to aid him in the solution of certain geological problems which have arisen in his work in California. I first took up the study of the collections which had been sent from California to the office at Washington, and afterward visited Philadelphia, New York, Boston, and New Haven, to make comparative studies. Finally I have come to California for the purpose of making a series of supplementary observations in the field, and in that work I am still engaged.

I am, with respect, your obedient servant,

C. A. WHITE,
Paleontologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. CHARLES D. WALCOTT.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., July 1, 1884.

SIR: In conformity with the request contained in your letter of June 10, 1884, I have the honour to present the following report of operations conducted under my charge during the fiscal year ended June 30, 1884.

The chief subjects of field investigation were the comparative study of local Devonian sections and their contained faunas in western New York; the taking of sections of the Paleozoic rocks near Cumberland Gap, Tenn., and White Sulphur Springs, W. Va.; the study of the Cambrian rocks in northeastern New York and western Vermont, and the collecting of Cambrian fossils in Wisconsin and Alabama.

Prof. Henry S. Williams was, by your instructions, placed in charge of the comparative study of the Devonian sections and fauna of western New York, and reports that on the 2d day of July he entered upon field-work, accompanied by Mr. C. S. Prosser, a graduate student of Cornell University, as an assistant.

He began at Batavia, Genesee County, New York, in the limestones of the Corniferous period, and examined exposures for the purpose of collecting from each fossiliferous zone as full a representation of the species as practicable, also rock specimens of each of the successive strata which presented any lithologic variation from those below. In this manner a region from 10 to 15 miles wide was explored across Genesee, Wyoming, and Allegany, and parts of Erie and Cattaraugus counties, New York, and a part of McKean County, Pennsylvania. The series of sections extended, geologically, from the base of the Devonian up to the Alton coal beds in McKean County, Pennsylvania, which is well up in the Carboniferous. Collections were made and sections examined and recorded. Also, during the summer, materials were collected in Oneida, Madison, and Otsego counties, and their stratigraphic relations recorded by Mr. Prosser.

The material gathered during the summer was taken to the paleontological laboratory at Cornell University, and there arranged and studied to determine the composition and sequence of the several faunas from the top of the Hamilton Group to the first coal deposit, along the meridian of 70° 30′, and their relations to their stratigraphic conditions. In working up the collections he was materially aided by the liberality of the trustees of Cornell University, who allowed the free use of their library and collections, and permitted him to associate his work with University duties, and also co-operated with him in gathering such literature and other facilities as were needed in promoting the investigation.

Mr. Ira Sayles reports that, acting under instructions received July 2, 1883, from the Director of the Geological Survey, he made a geologic

examination of the region about Cumberland Gap, Tenn., for the purpose of identifying the geologic section made in that vicinity by Prof. James M. Safford. He was further instructed to take sections to the north and south, so as to cover the entire Paleozoic section from the Carboniferous to the Archean.

In executing this work Mr. Sayles made extensive observations and numerous local sections in Lee County, Virginia, and Claiborne, Hancock, Hawkins, Green, Anderson, Knox, Jefferson, and Coke counties, Tennessee.

Late in the season Mr. Sayles examined an area of country north of Knoxville, Tenn., for the purpose of collecting fossils from the Cambrian (Knox shale), but was prevented from accomplishing his object by bad weather. During November and December, 1883, and up to January 25, 1884, he made a detailed study of the geology about Centreville, Hickman County, Tennessee, returning to Washington January 30. Since returning, the writing out of field-notes, drafting of stratigraphic sections, and the preparation of the collections for study has occupied his time to the present date.

Mr. H. R. Geiger reports that, acting under instructions from you, he selected as his first point of taking a section of the Paleozoic rocks from the Archean of the Blue Ridge across to the Coal Measures of West Virginia a station near the White Sulphur Springs, West Virginia.

In studying the Devonian rocks of this vicinity he extended his line of observations from Lewisburg, 12 miles west of White Sulphur Springs, to the Lewis tunnel on the Chesapeake and Ohio Railroad, and on east 8 miles, taking in a section of country from 3 to 4 miles in width. A second section was taken near Clifton Forge, 30 miles further east, for the purpose of crossing the Upper Silurian formations. After this he continued to the east, over the Blue Ridge, taking local sections in Rockbridge, Augusta, and part of Rockingham counties, Virginia.

On returning from the field, Mr. Geiger wrote out his field-notes, and during the latter part of the year he was employed in arranging the collections of Devonian fossils in the National Museum, and in the preparation and preliminary study of Devonian fossils collected by him in Virginia, and by Mr. C. Curtice in western New York.

Mr. L. C. Wooster was engaged during portions of July and August in collecting fossils from the Wisconsin Potsdam sandstones. A fine series of fossils was obtained from several typical localities, and a number of species new to the paleontologist were added to the fauna.

Mr. A. M. Gibson collected a quantity of material from the Upper Cambrian (Knox shale) in northern Alabama, during portions of the months of April and May, with fair results.

My own time was given, during the month of July and the early part of August, to the continuation of the preparation of a report on the Paleontology of the Eureka District, Nevada; in addition, notes were written out on the Paleozoic sections in the Grand Cañon of the

Colorado, and the outlines of the geologic formations exposed within the portion of the cañon studied during the winter of 1882–'83 were plotted on Mr. S. H. Bodfish's map of the Grand Cañon.

Immediately after completing the map, field-work on the Cambrian system in New York was begun, in accordance with your instructions, in the vicinity of Saratoga Springs, and continued north along the eastern base of the Adirondack Mountains into Warren, Essex, and Clinton counties. Crossing the lower end of Lake Champlain, a careful study was made of the Cambrian formations in Franklin County, Vermont. Many sections were taken, in both New York and Vermont, and a large number of paleontologic specimens were collected.

Mr. Cooper Curtice accompanied me as assistant, and on our return stopped at Troy, N. Y., to make a collection of Cambrian fossils from the hills east of that city.

Returning to Washington October 13, work was at once resumed on Paleontology on the Eureka District and continued until February 25, 1884, the date when the volume was transmitted for publication.

During the preparation of the Eureka report considerable time was given to a preliminary study of the Cambrian fauna of the Tonto formation of the Grand Cañon of the Colorada, and the Potsdam formation of New York.

Through the co-operation of Prof. Henry S. Williams, professor of paleontology at Cornell University, the loan of the Hartt collection of Cambrian fossils from the St. John formation, New Brunswick, was obtained from the trustees of the university. A study was then made of the type specimens contained therein, and an illustrated paper was prepared, to be published in the form of a bulletin of the Geological Survey.

It being desirable to continue the study of the Lower Cambrian fauna, I visited Boston, Mass., and, through the curator in charge, Prof. Alpheus Hyatt, obtained the use of material in the Museum of the Boston Society of Natural History from the Braintree argillites near Boston. Prof. Alexander Agassiz gave access to and the use of the collections in the Museum of Comparative Zoology at Cambridge, and Prof. N. S. Shaler kindly offered the use of a number of fine specimens. With the material thus generously placed at my service, and also specimens received from Dr. J. S. Newberry and Prof. Jules Marcou, the fauna of the Braintree argillites was studied, and the descriptions and illustrations added to the paper on the St. John fauna. This paper was transmitted for publication June 30, 1884.

As honorary curator in charge of the collections of invertebrate Paleozoic fossils of the United States National Museum, attention was given, at various times during the year, to the arrangement of the collections, and a large amount of material collected by the Geological Survey has been labeled and transferred to the Museum. This included the invertebrate fossils of the Devonian system in central

Nevada, exclusive of the corals. A collection of Devonian fossils from the Hamilton Group of western New York was also transferred.

The Nevada collection contained: Brachiopoda, 89 species, 1,549 specimens; Lamellibranchiata, 44 species, 240 specimens; Gasteropoda, 40 species, 275 specimens; Pteropoda, 11 species, 100 specimens; Cephalopoda, 9 species, 79 specimens; Crustacea, 3 species, 33 specimens, and Pœcilopoda, 7 species, 121 specimens; a total of 203 species and 2,397 specimens; and the New York collection a total of 1,577 specimens, representing 62 genera and 118 species. Full lists of both these collections have been furnished to you, that of the former with my report for the month of March and that of the latter with my report for April, 1884.

The Director of the National Museum has given every facility for the prosecution of work in the office, and the collections of the Museum were constantly used in making comparisons and in original studies.

Early in June the printing of the Paleontology of the Eureka District was begun, and my time up to the present has been fully occupied in attending to its publication.

By your permission I have published the following articles, which give results of studies made during the year.

"The Cambrian System in the United States and Canada." (Bull. Phil. Soc. Washington, vol. vi, p. 98.)

"Pre-Carboniferous Strata in the Grand Cañon of the Colorado, Arizona." (Amer. Jour. Sci., vol. xxvi, p. 437).

"Appendages of the Trilobite." (Science, vol. iii, p. 279).

Very respectfully, your obedient servant,

CHARLES D. WALCOTT,
Paleontologist.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. LESTER F. WARD.

UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., June 30, 1884.

SIR: I have the honor to submit the following report of the operations of my division during the fiscal year.

On the 8th of July, 1883, I left Washington, and proceeded under your instructions of June 21, 1883, to Glendive, Mont., taking with me Mr. Richard Foster as my assistant and as guide to certain localities in that vicinity visited the previous year by Dr. C. A. White's party, of which he was a member. Reaching Glendive on the 12th, an outfit was at once procured, and I proceeded to investigate the localities from which fossil plants belonging to the Fort Union Group had been ob-

tained and from which it was desirable to make more complete collections. These localities, in the order in which they were taken up, were as follows:

1. Iron Bluff, right bank of the Yellowstone River, 13 miles above Glendive.

2. Cracker Box Creek, left bank of the Yellowstone, 18 miles above Glendive and 5 miles back from the river.

3. Clear Creek, left bank of the Yellowstone, 14 miles above Glendive and 6 miles back from the river.

4. Burns's Ranch, left bank of the Yellowstone and at the water's edge, 28 miles below Glendive.

5. Gleason's Ranch, on Seven-Mile Créek, 10 miles below Glendive and 6 miles back from the river.

In addition to the special study of these five definite localities, excursions were made in various directions to some distance from each, and intermediate points were carefully examined. Fossil plants were found in greater or less abundance at all these places, and very large collections of fine specimens were made and taken to Glendive for shipment to Washington. The time consumed in this work was thirty-days, and the outfit was given up on the 12th day of August.

Leaving the work of boxing the fossils to Mr. Foster, I left Glendive on the 14th for Fort Benton, to join Dr. White, pursuant to previous arrangement. In co operation with him and his party I visited, on the 19th and following days, the Great Falls of the Missouri, 40 miles above Fort Benton, to study the formation at that place, and on the 22d we commenced the descent of the river from Fort Benton in an open boat. The voyage was continued to Bismarck, a distance by the steamboat schedule of 1,059 miles, and occupied just thirty days, the party reaching Bismarck on September 21. It proved of great interest and value from a geologic point of view, and fossil plants were collected at all points where they could be found.

The most notable locality discovered is about 7 miles below Coal Banks, on the right bank of the river, in dark carbonaceous ironstone, occupying a stratigraphic position near the base of the Fox Hills and probably in the Fort Pierre Group of Meek and Hayden. Determinable dicotyledonous impressions were here detected, which are of interest as being the only Cretaceous fossil plants thus far found within the United States above the Dakota Group. Characteristic plants of the Fort Union Group were collected at different points between Poplar Creek Agency and Bismarck.

From Bismarck I returned to Washington, arriving September 25.

Before leaving for the field I had instructed Mr. G. O. Chaney, whom you had temporarily assigned to my division, in the work of cataloguing the books on fossil plants which had been commenced in the spring, and during my absence he had performed this work in a very satisfactory manner considering its nature and the want of any

supervision. He continued in this line of work until near the time of his resignation, which was at the end of December.

While awaiting the arrival of my collections I was chiefly occupied in unpacking, classifying, and installing a large collection which had come into my hands, through the National Museum, from Mr. Lesquereux. They are chiefly from Florissant, Colo., and from near Green River, Wyoming.

The materials which I had shipped from Glendive, Mont., and Bismarck, Dak., had all arrived before the end of October, but delays in unpacking them were occasioned by lack of the necessary cases and trays. It was not until the end of December that the fossils of the season's collections were fairly unpacked and placed in drawers.

On the 1st of January I began their systematic arrangement and detailed study, and to this I have devoted a large portion of my time since that date.

On the 14th of January Mr. A. E. Murlin, of the topographical division, was detailed to assist me, and besides doing a large amount of Museum work incident to the curatorship of fossil plants in the National Museum, including the preparation of a much-needed card catalogue of the species now on hand in the Museum, he has thoroughly washed all the specimens in the collections of last season, which was a necessary prerequisite to their successful study.

On January 29 you were so good as to appoint, upon my recommendation, Mr. Osborne Ward, and assign him to my division to take up and carry on the work upon the proposed catalogue of fossil plants, which had been necessarily suspended since early in December. In my last annual report I gave a brief account of the object and plan of this undertaking, which is designed to constitute a digest of the history and present status of the science of Paleobotany from both the geognostic and the biologic points of view. Such a work, though highly important and almost indispensable to the proper utilization of American material for geologic purposes, must, as you can readily see, deal chiefly with the literature of the subject. I have hitherto met with a serious obstacle in this work from the lack of assistants capable of handling the literature intelligently, it being to so large an extent in foreign languages. This appointment entirely obviates this difficulty, and enables me to intrust to Professor Ward's charge the entire work of compiling this volume.

The only part of this work to which I had expected to give special personal attention was an introductory chapter embodying certain general considerations. Much material for this chapter had been collected, and a portion of the discussion had already been outlined for over a year. When, therefore, in the early part of March you requested me to furnish a short contribution to your next annual report, I informed you, upon due reflection, that, if acceptable, I would endeavor to present for this purpose a preliminary draft of this introduction, and that

although the data for preparing it would be somewhat less complete than at a later stage, still it would substantially represent the present condition of our knowledge of fossil plants, while its subsequent correction and completion would not be difficult. Conformably to this promise I herewith submit the manuscript of this paper, which I ask you to accept as the only contribution I have been able to make, and which I hope may be satisfactory.

Ensign E. E. Hayden, U. S. N., on duty at the National Museum and assigned to the department of fossil plants, commenced in March to figure the types of my last season's collections. Unsteadiness of hand, incident to the recent amputation of his leg and consequent nervous prostration, led him to investigate improved methods of illustration, particularly the aids derivable from photography, and, after intelligent reflection and some ingenious experiments, with the co-operation of Mr. Hillers, he has succeeded in the practical application of photography to the illustration of fossil plants.

For the last two months I have been compelled for the most part to suspend work upon the collections and devote my entire time to the completion of the memoir which I had promised for the Annual Report, and which I was informed must be ready on July 1. It has involved an unexpectedly large amount of bibliographic research, and in this respect there is still much to be desired. I was also obliged to cause a suspension of the regular work of cataloguing the books and to employ the entire force in arranging the data thus far obtained for the preparation of the tables that accompany this paper. About 25,000 index slips had been written, including all the more important and many of the smaller works and memoirs on the subject. Among those in the former class is Schimper's "Traité de paléontologie végétale," in three volumes, which is by far the most general work on the fossil plants that has ever appeared. But aside from the fact that the last volume of this work was published ten years ago, and that it embraces little of the labors of the past fifteen years in this field, and hence scarcely anything from this side of the Atlantic, its other deficiencies have become very apparent as our work has progressed, showing the pressing need, not merely of a substitute, but of something more than a substitute, not so much a *manual* as a *compendium* of the science.

It may not be inappropriate, in closing this report, to append the following brief analysis of the contents of the proposed work:

I. Introductory general discussion.

II. Systematic catalogue of all the fossil plants that have thus far been described, accompanied by a complete synonymy and references to work, page, plate, and figure.

III. Catalogue (without synonymy or references) of all species found at each geologic horizon.

IV. Lists of strictly characteristic species for each horizon.

V. Alphabetic list of all localities showing geologic formations.

VI. Bibliography (as complete as possible).

VII. Alphabetic list of abbreviations of titles.

VIII. Full species index, distinguishing synonyms.

IX. Map, or maps, showing all the localities from which fossil plants have been reported, and indicating the geologic horizon of each by appropriate colors.

Other features of secondary importance will be introduced which need not be enumerated here.

It is earnestly desired to have this work ready for publication at the end of the coming fiscal year, but a large amount of work still remains to be done, and thoroughness and completeness are deemed more important considerations than speed.

Very respectfully, your obedient servant,

LESTER F. WARD,
Geologist United States Geological Survey.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. F. W. CLARKE.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF CHEMISTRY,
Washington, June 30, 1884.

SIR: I have the honor to submit the following report of work done in the division of chemistry during the fiscal year 1883–'84.

Previous to this year the chemical work of the Survey was carried on either in laboratories attached to separate field-divisions, and under their independent control, or by chemists outside of the Survey who were specially employed for particular investigations or analyses. The growth of the Survey, however, rendered necessary the organization of a central laboratory at Washington; and, with such organization in view, on the 1st day of July, 1883, I entered upon my duties as chemist.

As a good chemical laboratory had already been established by the United States National Museum, it was deemed advisable by yourself and Professor Baird to start the new division of chemistry upon a basis of co-operation with the Museum. Accordingly, the existing laboratory was placed in my custody, additional apparatus and supplies were imported, and early in December the regular chemical work began. The branch laboratory at Salt Lake City was discontinued, and its outfit was transferred to Washington; but the laboratories at Denver and San Francisco still remain in independent operation, attached to the divisions of Messrs. Emmons and Becker, respectively.

The Washington laboratory, as at present arranged, consists of two large rooms and two small rooms on the second floor of the southwest

pavilion of the National Museum. One of the larger rooms is equipped for general chemical operations, analytical work in particular, and the other serves for assaying and furnaces. Of the smaller rooms, one contains the balances and the second is used as an office. The space has been ample so far, but must be enlarged as our work becomes more extensive. The outfit of apparatus and chemicals is exceedingly good, and includes the rich supply of platinum utensils which were formerly used in the Census and Survey laboratory at Newport. Additional platinum was bought of the Northern Transcontinental Survey at the time of its discontinuance, and several choice pieces were also purchased from the estate of the late J. Lawrence Smith.

From the beginning of laboratory operations I have been ably assisted by Dr. Thomas M. Chatard. In April, Dr. Frank A. Gooch was added to the laboratory force, and has since been specially assigned to work upon the Yellowstone Park collections of Mr. Arnold Hague. I have also had for a short time the services of Dr. Henri Erni, and two laborers have been employed continually in the manual work of the laboratory.

The duties of the division of chemistry proper may be divided into two essential parts. First, the execution of the routine analyses required by other divisions of the Survey. These include the examination of waters, rocks, minerals, clays, sediments, incrustations, and so on. Second, the conduct of strictly scientific researches upon problems relating to geological chemistry and mineralogy. Each line of work is of direct importance to the Survey, and neither could be neglected without detriment to the general interest. During this year, necessarily, much of my own time has been taken up with details of organization; but a reasonably large amount of strictly chemical work has nevertheless been accomplished. A considerable number of analyses have been completed, some researches are well under way, and some field investigations relating to points in mineralogical chemistry have been fairly started.

Naturally, analytical work has occupied the larger part of my attention since December. In all, about one hundred and fifty analyses, qualitative and quantitative, have been made and reported. For the division of the Great Basin, in addition to a number of rocks, sediments, clays, and incrustations, the following waters have been analyzed: City Creek, Utah; Bear River, Utah; Utah Lake, Utah; Pyramid Lake, Nevada (four samples); Winnemucca Lake, Nevada; Walker Lake, Nevada (two samples); Walker River, Nevada; Humboldt River, Nevada; Hot Spring, foot of Granite Mountain, Nevada; Hot Spring, at Hot Spring Station, Nevada; Soda Lake, Ragtown, Nevada, (two samples); Mono Lake, California; spring on Tufa Crag, Mono Lake, California; Warm Spring, Warm Spring Station, Mono Basin, California; Boiling Spring, Honey Lake Valley, California; Lake Tahoe, California.

For the Yellowstone Park Survey of Mr. Arnold Hague, analyses have been made of seven rocks, four geyser waters, and the water of Alum Creek. For Dr. A. C. Peale, the waters of the Livingston Warm Springs, Helena Hot Springs, Warm Springs of Emigrant Gulch, and Mill Creek Cold Spring, all in Montana, have been analyzed. Waters from the Utah Hot Springs near Ogden, and six of the Virginia Hot Springs (Bath County), have been fully reported upon. Details concerning these analyses will appear in forthcoming laboratory bulletins. The complete water analyses number thirty-seven, apart from a larger number of partial and qualitative examinations.

A number of rocks collected by Mr. J. S. Diller in California have occupied much of our attention. Of these, three represented the dacites of Lassen's Peak, one was a saussurite gabbro from Shasta County, and one a basalt from Pit River. From Mount Thielson, in Oregon, the basalt, four of its component minerals, and a fulgurite formed by the fusion of the basalt by lightning, were all analyzed.

For purely mineralogical purposes the following analyses have been made: Gahnite from Montgomery county, Maryland; allanite from Topsham, Me.; beryl from Greene county, Tennessee; damourite (two varieties) from Stoneham, Me.; margarite from Gainesville, Ga., and Iredell county, North Carolina; halloysite from California; prochlorite from Georgetown, D. C.; cimolite from Norway, Me.; alunogen and halotrichite from Grant county, New Mexico.

Each of these minerals represents some new locality or mode of occurrence, and has special scientific interest. The alunogen and halotrichite from New Mexico are said to occur in enormous quantities over an area of two thousand acres, and are likely to have in the future an economic importance.

In addition to the foregoing minerals, two Alaskan specimens of remarkable interest were investigated. These were two alleged "jade" implements obtained by the U. S. Signal Service expedition from the Eskimo of Point Barrow.

A moderate amount of work has been done in the assay of various ores, but no details concerning it need be cited here. By myself a research has been begun relative to the chemical structure of the silicates, and especially of those silicates which have importance as rock-forming minerals. Of the latter, the alteration products will be studied systematically; but of course much time must elapse before any connected report of the results can be made.

By Dr. Chatard an important investigation has been carried out to completion upon the use of bismuth trioxide in the analysis of silicates. The process is a modification and an improvement of one proposed a few years ago by Hempel, and gives us a much better method for the quantitative estimation of alkalies in silicates than any heretofore in use. The details of the process will appear in our forthcoming bulletin.

Other experiments having in view the improvement of analytic methods ods are still in progress.

In connection with our mineralogical studies, some field-work has been undertaken. During the last week of July, 1883, I visited a new group of mica mines in Ashe County, North Carolina, and collected some interesting material. In August and September, during an absence from Washington of nearly four weeks, I examined the mica deposits at Alstead and Grafton, N. H., and in Maine I visited the feldspar quarries of Topsham, and the tourmaline localities at Auburn, Hebron, Paris, and Norway. In October I examined still another mica mine 12 miles north of Washington, in Montgomery County, Maryland, and in March a second mine near Laurel in Howard County. These Maryland mines are but two of a group recently opened, and they resemble in the closest manner the mica localities of New England and North Carolina. Considered altogether, the mica mines of the Appalachian system offer for study some interesting problems in associative mineralogy, and it is with these problems that the division of chemistry has to do. In the granite veins which yield merchantable mica, such rare elements as glucinum, cerium, yttrium, columbium, tantalum, uranium, etc., chiefly occur; and nearly every thorough exploration for mica brings to light some of the minerals containing them. It is my intention to continue field researches along the mica belt, from Maine to Alabama, and I hope in due time to present a report concerning it.

At the beginning of the fiscal year the physical laboratory of the Survey was attached to the division of chemistry. In that laboratory, which is at present situated at New Haven, Drs. Carl Barus and William Hallock have continued their researches upon the measurement of high temperatures. Their chief work has been in the direction of developing thermo-electric methods, and their results will soon be ready as a separate bulletin. Their investigations, especially as regards the use of thermo-couples of platinum and platin-iridium alloys, have been quite successful. During the latter part of the summer and the early autumn, Dr. Hallock was absent from the laboratory on field-duty in the Yellowstone National Park. His results, which relate to the physics of geyser action, will appear in Mr. Hague's report. During his absence his place in the laboratory was filled by Mr. Arthur B. Cornwall, whose services were of a highly satisfactory character.

During the winter, a part of Dr. Barus's time was spent in continuing the experiments of Prof. W. H. Brewer on the conditions of subsidence of very fine particles suspended in liquids.

Very respectfully,

F. W. CLARKE,
Chief Chemist.

Hon. J. W. POWELL,
Director, U. S. Geological Survey, Washington, D. C.

REPORT OF MR. ALBERT WILLIAMS, JR.

UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF MINING STATISTICS AND TECHNOLOGY,
Washington, D. C., June 30, 1884.

SIR: The manuscript of the statistical report for 1882 and the first six months of 1883 was submitted to you July 2, 1883, and was placed in the hands of the Government Printer within a few days. The proof correction of that volume was finished in the first week of August, but owing to delays in the press-work and binding, the report was not issued till October 15. As the value of statistics depends so largely upon the promptness with which they are presented, pending the publication of the full report the leading results of the investigation were given to the press and the public in an abridged form on August 2.

No allotment having been made for the prosecution of statistical work during the fiscal year just closed, a report has not been issued for 1883; but the statistics for that year, together with those for 1884, will be ready for a volume to appear early in 1885, the material for which is now being collected, a part of the descriptive and technical matter being already in shape. The forthcoming report is being prepared on the same general system as that adopted last year. Without repetition of text the record for previous years will be preserved, and the tabulation will be extended backward to the beginnings of the several mineral industries in all cases where reliable data are accessible, the aim being to present a complete history of the production in each instance. In the technical branch of the inquiry the matter offered is fresh, relating mainly to new methods and present practice not hitherto described. It is intended to add a series of statistical charts, illustrating the tabulated results.

I desire again to call attention to the most encouraging feature of this work—the interest and public spirit shown by miners, engineers, metallurgists, geologists, and dealers in mineral products, without whose active co-operation the attempt to cover so wide a field with the means at disposal would be hopeless.

While there has been a marked decline in traffic and prices in some of the metal industries of late, this has been largely due to the curtailment of speculative enterprises, and I do not find in the statistics thus far gathered any indication of a serious or general decline in production or prosperity, nor of immediate danger from over-production. Still, the rapid development of some of the more important mineral and metal industries, notably those of coal, iron, copper, and lead, has brought matters to a point where the closest economy and best practice are enforced upon producers to enable them to maintain profits, and where,

too, the smaller establishments are at a growing disadvantage as compared with the larger.

During the past year, in addition to work preparatory to the issue of the report for 1883–1884, I have been engaged in studying the systems of classification of the massive rocks, and in the arrangement and proof-correction of the Census volume on the "Statistics and Technology of the Precious Metals," which was prepared under the direction of officers of the Geological Survey.

Very respectfully, your obedient servant,

ALBERT WILLIAMS, JR.,
Geologist in charge.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

REPORT OF MR. GEORGE W. SHUTT.

UNITED STATES GEOLOGICAL SURVEY.
Washington, July 22, 1884.

SIR: In compliance with instructions, I submit the following as a partial report of the progress of the work under my charge during the preceding fiscal year.

Leaving Washington the 15th of June, 1883, I went to Loudoun County, Virginia, where I remained until the 9th day of July, and from thence, by team, I proceeded to Winchester, from Winchester to Staunton, and from Staunton to Charleston, the capital of West Virginia, arriving at that point on the 19th day of the month, the distance traversed being about 350 miles, passing on my way through the counties of Clarke, Frederick, Shenandoah, Rockingham, Augusta, Bath, and Alleghany, in Virginia, and Greenbrier, Fayette and Kanawha, in West Virginia.

The necessary time for organizing the state of West Virginia, so as to secure local information from private sources by correspondence and otherwise, was spent in Charleston. After its completion I proceeded, by team, through Fayette County, north of the New River, through Nicholas, county, up the Gauley, crossing it at the mouth of the Cranberry River, and following that river and its tributaries, the Cranberry, Cherry, and Williams, to their headwaters; from thence across to the Elk, at Webster Court-House; thence along its line, through Braxton and Clay counties; from thence, via Webster Court-House, to the Tigart Valley River, a tributary of the Monongahela in Randolph County, and proceeded up that river for about 30 miles; from thence, via Staunton and Parkersburg pike, across the headwaters of Shaver's fork of the Cheat, that river flowing on the top of the Cheat Mountain about 1,200 feet above the Tigart Valley River, 10 miles east of it, and about 1,000 feet above the Greenbrier River, 7 miles west of it; from thence to the

Greenbrier River in Pocahontas County; from thence down that river to Huntersville, the county-seat; from thence down Anthony's Creek and the main Alleghany range to Greenbrier White Sulphur Springs, the distance traversed during the month of August exceeding 700 miles, by team and on horseback, and nine-tenths of it through an unbroken wilderness of magnificent forest, containing a large number of the most valuable hard and soft woods, and exhibiting remarkable girth of tree, height to limb, and density of growth.

After reaching Lewisburg, in Greenbrier County, I returned to Charleston, to complete the organization of the state by counties. On the 10th of September, having finished that branch of my work, I returned to Lewisburg, and from thence, by team, passed through Monroe County, via Red Sulphur Springs, and down the New River through Summers County, and thence across Raleigh County, via Raleigh Court-House, over the Guyandotte Mountains, down the Clear fork of the Guyandotte River to its junction with Laurel fork, near Oceana, the county seat of Wyoming County; from thence across the Laurel fork of the Guyandotte to the Guyandotte River, and up that river to its headwaters, between the Guyandotte and the Flat Top Mountains; thence along the plateau of the Flat Top and its eastern slope for nearly 50 miles to the Blue Stone River, a tributary of the New at its eastern base, from thence to Princeton, the county seat of Mercer County, and from that point along the base of the East River Mountains to a divide running with the regular chain of mountains between the headwaters of the New and the Clinch Rivers; from thence to Jeffersonville, in Tazewell County, Virginia; from thence up tributaries of the Clinch and down the Dry fork of the Tug River to Peeryville, the county seat of McDowell County, West Virginia, that being the only road by which the county seat is accessible by wagon; from thence back to Tazewell Court-House; from thence across Bland County, and through Smythe County, on the headwaters of the Holston River, to Wytheville, in Wythe County, Virginia; from thence to Pulaski County, crossing the New River in that county, to Montgomery County; from thence, crossing the divide between the New River and the Roanoke River, to Roanoke, the junction of the Shenandoah Valley Railroad, and the Norfolk and Western Railroad; from thence across the divide to James River, at Lexington, in Rockbridge County, Virginia; from thence across the divide to the headwaters of the Shenandoah River and to Staunton, in Augusta County; from thence down the Shenandoah Valley, on the eastern side to the Massanutten Mountains, through the counties of Rockingham, Page, Shenandoah, Frederick, and Clarke to Round Hill, in Loudoun County. The distance traversed by team and on horseback during the months of September and October exceeded 1,200 miles, and the summer's researches covered a large portion of the wilderness region of West Virginia and southwest Virginia.

The greatest part of the area through which I traveled is undescribed and but little known. No accurate methods have been adopted to map it or to secure knowledge of its physical features. Through the co-operation of the office a thorough system of correspondence has been carried on during the last fiscal year with officials and other citizens of the different counties of the two states, attention being especially directed to the wilderness or unknown region. This has secured a vast amount of information in regard to its forest characteristics, and also county maps and reports of great value; while some of the maps are rude, perhaps half of them reach a high degree of accuracy, and the reports and maps corroborate my own conclusions and enable me to submit a statement with confidence. Detailed reports from sixty counties and maps from forty-two counties in the two states are in my possession. This branch of the work has been free of cost except that entailed in carrying on correspondence, and the office is greatly indebted to gentlemen in the two states who have so kindly responded.

I am preparing a table of statistics, exhibiting the value of the different kinds of lumber produced by the forests of this region in the different markets of the world.

I am preparing as rapidly as possible a detailed report on each locality of the two states, to be accompanied by a map and by a comprehensive system of statistics.

Very respectfully,

GEO. W. SHUTT,
General Assistant.

Hon. J. W. POWELL,
Director U. S. Geological Survey, Washington, D. C.

DEPARTMENT OF THE INTERIOR, UNITED STATES GEOLOGICAL SURVEY.

PAPERS ACCOMPANYING THE ANNUAL REPORT

OF THE

DIRECTOR OF THE U. S. GEOLOGICAL SURVEY

FOR THE

FISCAL YEAR ENDING JUNE 30, 1884.

THE TOPOGRAPHIC FEATURES

OF

LAKE SHORES.

BY

G. K. GILBERT.

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THE TOPOGRAPHIC FEATURES OF LAKE SHORES.

BY G. K. GILBERT.

I.—INTRODUCTION.

The play of meteoric agents on the surface of the land is universal and there is a constant tendency to the production of the forms characteristic of their action. All other forms are of the nature of exceptions and attract the attention of the observer as requiring explanation. The shapes wrought by atmospheric erosion are simple and symmetric, and need but to be enumerated to be recognized as the normal elements of the sculpture of the land. Along each drainage line there is a gradual and gradually increasing ascent from mouth to source, and this law of ascending acclivity applies to all branches as well as to the trunk. Between each pair of adjacent drainage lines is a ridge or divide, [illegible] about midway and rounded at the top. Wherever two divides join there is a summit higher than the adjacent portions of each, [illegible] the highest summits of all are those which, measuring along lines of drainage, are most remote from the ocean. The crests of the divides are not horizontal, but climb from summit to summit. There are no sharp contrasts of slope; the concave profiles of the [illegible] change their inclination little by little, and they merge by a gradation into the convex profiles of the crests and summits. The system of slopes thus succinctly outlined is established by erosion under the general law of the interdependence of parts. [illegible] which opposes the maximum resistance to the erosive [illegible]

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I.—INTRODUCTION.

The play of meteoric agents on the surface of the land is universal, and there is a constant tendency to the production of the forms characteristic of their action. All other forms are of the nature of exceptions, and attract the attention of the observer as requiring explanation. The shapes wrought by atmospheric erosion are simple and symmetric, and need but to be enumerated to be recognized as the normal elements of the sculpture of the land. Along each drainage line there is a gradual and gradually increasing ascent from mouth to source, and this law of increasing acclivity applies to all branches as well as to the main stem. Between each pair of adjacent drainage lines is a ridge or hill standing about midway and rounded at the top. Wherever two ridges join there is a summit higher than the adjacent portion of either ridge; and the highest summits of all are those which, measuring along lines of drainage, are most remote from the ocean. The crests of the ridges are not horizontal, but undulate from summit to summit. There are no sharp contrasts of slope; the concave profiles of the drainage lines change their inclination little by little, and they merge by a gradual transition in the convex profiles of the crests and summits. The system of slopes thus succinctly indicated is established by atmospheric erosion under the general law of the interdependence of parts. It is the system which opposes the maximum resistance to the erosive agents.

The factor which most frequently, and in fact almost universally, interrupts these simple curves is heterogeneity of terrane or diversity of rock texture. Different rocks have different powers of resistance to erosion, and the system of declivities which, under the law of interdependence, adjusts itself to diversity of rock texture, is one involving diversity of form. Hard rocks survive, while the soft are eaten away. Peaks and cliffs are produced. Apices are often angular instead of rounded. Profiles exhibit abrupt changes of slope. Flat-topped ridges appear, and the distribution of maximum summits becomes in a measure independent of the length of drainage lines.

A second factor interrupting the continuity of erosion profiles is upheaval, and this produces its effect in two distinct ways. First, the

general uprising of a broad tract of land affects the relation of the drainage to its point of discharge or to its base level, causing corrasion by streams to be more rapid than the general waste of the surface and producing cañons and terraces. Second, a local uprising by means of a fault produces a cliff at the margin of the uplifted tract, and above this cliff there is sometimes a terrace.

A third disturbing factor is glaciation, the *cirques* and moraines of which are distinct from anything wrought by pluvial erosion; and a fourth is found in eruption.

The products of all these agencies except the last have been occasionally confused with the phenomena of shores. The beach-lines of Glen Roy have been called river terraces. The cliffs of the Downs of England have been ascribed to shore waves. Glacial moraines in New Zealand have been interpreted as shore terraces. Beach ridges in our own country have been described as glacial moraines, and fault terraces as well as river terraces have been mistaken for shore marks. Nevertheless, the topographic features associated with shores are essentially distinct from all others; and when their peculiar characters are understood there is little occasion for confusion. It is only where the shore record is faintly drawn that any difficulty need arise in its interpretation. In investigating the history of Lake Bonneville and other Quaternary water bodies of the Great Basin, the writer and his assistants have had constant occasion to distinguish from all others the elements of topography having a littoral origin and have become familiar with the criteria of discrimination. Their endeavor to derive from the peculiarities of the old shore lines the elements of a chronology of the lake which wrought them, has led them to study also the genesis of each special feature; and it is proposed to present in the following pages the results of this study.[1]

In the discussion of shore phenomena there is little room for originality. Not only has each of the elements which go to make up the topography of a shore been recognized as such, but its mode of origin has been ascertained. There appears, however, to be room for a systematic treatment of the subject in English, for it is only in continental Europe that its general discussion has been undertaken. The writings of Elie de Beaumont include a valuable contribution,[2] and Alessandro Cialdi has devoted a volume to the motion of waves and their action on coasts.[3] These cover a large portion of the ground of the present essay, but treat the subject from points of view so diverse that the essay would be

[1] Partial outlines of the subject have been presented by the writer in connection with various accounts of Lake Bonneville, and a fuller outline was published by Mr. I. C. Russell in a paper on Lake Lahontan in the Third Annual Report of the Geological Survey.

[2] Leçons de géologie pratique; Tome premier; Septième leçon, Levées de sable et de galet, pp. 221–252.

[3] Sul moto ondoso del mare e su le correnti di esso specialmente su quelle littorali pel comm. Alessandro Cialdi. Roma, 1866.

only partially superseded by their translation. The title of a work by H. Keller (Studien über die Gestaltung der Sandküsten) indicates another discussion of a general nature, but this I have not seen. American and British contributions are contained chiefly in the reports of engineers on works for the improvement of harbors and the defense of coasts. The most comprehensive which has fallen under my eye, and one at the same time of the highest scientific character, is contained in the annual report of the United States Coast Survey for 1869, where Prof. Henry Mitchell, in treating of the reclamation of tide lands, describes the formation of the barriers of sand and shingle by which these are separated from the ocean.

It is proper to add that the writer became acquainted with these works only after the body of this essay was prepared. The objective studies on which his conclusions are based had been completed, and the discussion had acquired nearly its present shape before he became aware of the extent of the affiliated literature. His conclusions have, therefore, the quality of independence, and, so far as they coincide with those of earlier writers, have a corroborative value.

The engineering works whose construction has led to local investigations of shores are chiefly upon maritime coasts, where tides exert an important influence, and the literature of lake shores is comparatively meager. It is true that the phenomena of lake margins are closely paralleled by those of tide-washed coasts, but this, unfortunately, does not render the literature of the latter the more applicable, for there is a tendency to ascribe to the action of tides features which the students of inland lakes are compelled to account for independently of that agent.

It should be noted also that the point of view of the civil engineer is somewhat different from that of the present study. He is, indeed, concerned with all the forms into which the shore material is wrought by the action of the waves, but he is not at all concerned with their internal structure; and he knows them, moreover, only as subaqueous banks to be determined by sounding, and not at all as features of the dry land. The geologic student has, too, some facilities for study which the engineer lacks, for he is frequently enabled to investigate the anatomy of shore structures by means of natural cross-sections, while the engineer is restricted to an examination of their superficial forms.

In the treatment of the subject the description and analysis of the elements of shore topography will be followed by the comparison of certain of these elements with simulating features of different origin. They will be preceded by a few words devoted to the consideration of shore shaping as a division of the more general process of earth shaping.

EARTH SHAPING.

The earth owes its spheroidal form to attraction and rotation. It owes its great features of continent and ocean bed to the unequal distribution of the heterogeneous material of which it is composed. Many of its minor inequalities can be referred to the same cause, but its details of surface are chiefly molded by the circulation of the fluids which envelope it. This shaping or molding of the surface may be divided into three parts—subaerial shaping (land sculpture), subaqueous shaping, and littoral shaping. In each case the process is threefold, comprising erosion, transportation, and deposition.

In subaerial or land shaping the agents of erosion are meteoric—rain, acting both mechanically and chemically, streams, and frost. The agent of transportation is running water. The condition of deposition is diminishing velocity.

In subaqueous shaping, or the molding of surface which takes place beneath lakes and oceans, currents constitute the agent of erosion. They constitute also the agent of transportation; and the condition of deposition is, as before, diminishing velocity.

In littoral shaping, or the modeling of shore features, waves constitute the agent of erosion. Transportation is performed by waves and currents acting conjointly, and the condition of deposition is increasing depth.

On the land the amount of erosion vastly exceeds the amount of deposition. Under standing water erosion is either nil or incomparably inferior in amount to deposition. And these two facts are correlatives, since the product of land erosion is chiefly deposited in lakes and oceans, and the sediments of lakes and oceans are derived chiefly from land erosion. The products of littoral erosion undergo division, going partly to littoral deposition and partly to subaqueous deposition. The material for littoral deposition is derived partly from littoral erosion and partly from land erosion.

That is to say, the detritus worn from the land by meteoric agents is transported outward by streams. Normally it is all carried to the coast, but owing to the almost universal complication of erosion with local uplift, there is a certain share of detritus deposited upon the basins and lower slopes of the land. At the shore a second division takes place, the minor portion being arrested and built into various shore structures, while the major portion continues outward and is deposited in the sea or lake. The product of shore erosion is similarly divided. A part remains upon the shore, where it is combined with material derived from the land, and the remainder goes to swell the volume of subaqueous deposition.

The forms of the land are given chiefly by erosion. Since the wear by streams keeps necessarily in advance of the waste of the interven-

ing surfaces, and since, also, there is inequality of erosion dependent on diversity of texture, land forms are characterized by their variety.

The forms of sea beds and lake beds are given by deposition. The great currents by which subaqueous sediments are distributed sweep over the ridges and other prominences of the surface and leave the intervening depressions comparatively currentless. Deposition, depending on retardation of currents, takes place chiefly in the depressions, so that they are eventually filled and a monotonous uniformity is the result.

The forms of the shore are intermediate in point of variety between those of the land and those of the sea bed; and since they alone claim parentage in waves, they are *sui generis*.

Ocean shores are genetically distinguished from lake shores by the co-operation of tides, which cannot fail to modify the work accomplished by waves and wind currents. The shores which constitute the objective basis of the present discussion were tideless; and the discussion is therefore limited to lake shores. It is perhaps to be regretted that the systematic treatment here proposed could not be extended so as to include all shores, but there is a certain compensation in the fact that the results reached in reference to lake shores have an important negative bearing on tidal discussions. It was long ago pointed out by Elie de Beaumont[4] and Desor[5] that many of the more important features ascribed by hydraulic engineers to tidal action, are produced on the shores of inland seas by waves alone; and the demonstration of wave-work pure and simple should be serviceable to the maritime engineer by pointing out the results in explanation of which it is unnecessary to appeal to the agency of tides.

The order of treatment is based on the three-fold division of the process of shore shaping. Littoral erosion and the origin of the sea cliff and wave-cut terrace will be first explained, then the process of littoral transportation with its dependent features, the beach and the barrier, and finally the process of littoral deposition, resulting in the embankment, with all its varied phases, and the delta.

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[4] Leçons de géologie pratique, Paris, 1845, v. 1, p. 232.

[5] Geology of Lake Superior Land District by Foster & Whitney, Washington, 1851, v. 2, pp. 262, 266.

II.—WAVE WORK.

LITTORAL EROSION.

In shore sculpture the agent of erosion is the wave. All varieties of wave motion which affect standing water are susceptible of producing erosive effect on the shore, but only those set in motion by wind need be considered here. They are of two kinds: the wind wave proper, which exists only during the continuance of the wind; and the swell, which continues after the wind has ceased. It is unnecessary to discriminate the effects of these upon the shore further than to say that the wind wave is the more efficient and therefore the better deserving of special consideration. In the wind wave two things move forward, the undulation and the water. The velocity of the undulation is relatively rapid; that of the water is slow and rhythmic. A particle of water at or near the surface, as each undulation passes, describes an orbit in a vertical plane, but does not return to the starting point. While on the crest of the wave it moves forward, and while in the trough it moves less rapidly backward, so that its residual advance is the excess of the one movement over the other.[6]

This residual advance is the initiatory element of current. By virtue of it the upper layer of water is carried forward with reference to the layer below, being given a differential movement in the direction toward which the wind blows. This movement is gradually propagated to lower aqueous strata, and ultimately produces movement of the whole body, or a wind-wrought current. So long as the velocity of the wind remains constant, the velocity of the current is less than that of the wind, and there is always a differential movement of the water, each layer moving faster than the one beneath. The friction is thus distributed through the whole vertical column, and is even borne in part by the lake bottom. The greater the depth the smaller the share of friction each layer of water is called upon to bear and the greater the velocity of current which can be communicated by a given wind. The height of waves is likewise conditioned by depth of water, deep water permitting the formation of those that are relatively large.

When the wave approaches a shelving shore its habit is changed. The velocity of the undulation is diminished, while the velocity of the advancing particles of water in the crest is increased; the wave length, measured from trough to trough, is diminished, and the wave height is

[6] The theory of wave motion involved in this and the following paragraphs is based partly on observation but chiefly on the discussions of Scott Russell, Airy, Cialdi, and Rankine.

increased; the crest becomes acute, with the front steeper than the back; and these changes culminate in the breaking of the crest, when the undulation proper ceases. The return of the water thrown forward in the crest is accomplished by a current along the bottom called the *undertow*. The momentum of the advancing water contained in the wave-crest gives to it its power of erosion. The undertow is efficient in removing the products of erosion.

When the land at the margin of the water consists of unconsolidated material or of fragmental matter lightly cemented, the simple impact of the water is sufficient to displace or erode it. The same force is undoubtedly competent also to disintegrate and remove firmer rock that has been superficially weakened by frost, but it may be doubted whether it has any power to wear rock that is thoroughly coherent. The impact of large waves has great force, and its statement in tons to the square foot is most impressive; but, so far as our observation has extended, the erosive action of waves of clear water beating upon firm rock is practically nil.[7]

It rarely happens, however, that the impact of waves is not reinforced by the impact of mineral matter borne by them. The detritus worn from the shore is, of course, always at hand to be used by the waves in continuance of the attack; and to this is added other detritus carried along the shore by a process presently to be described.

The rock fragments which constitute the tool of erosion are themselves worn and comminuted by use until they become so fine that they no longer lie in the zone of breakers but are carried away by the undertow.

The direct work of wave erosion is restricted to a horizontal zone dependent on the height of the waves. There is no impact of breakers at levels lower than the troughs of the waves; and the most efficient impact is limited upward by the level of the wave crests, although the dashing of the water produces feebler blows at higher levels. The indirect work has no superior limit, for as the excavation of the zone is carried landward, masses higher up on the slope are sapped so as to break away and fall by mere gravity. Being thus brought within reach of the waves, they are then broken up by them, retarding the zonal excavation for a time but eventually adding to the tool of erosion in a way that partially compensates.

Let us now consider what goes on beneath the surface of the water. The agitation of which waves are the superficial manifestation is not restricted to their horizon, but is propagated indefinitely downward. Near the surface the amount of motion diminishes rapidly downward, but the rate of diminution itself diminishes, and there seems no theoretic reason for assigning any limit to the propagation of the oscillation.

[7] On the shores of Lake Bonneville not only was there no erosion on the faces of cliffs at points where the waves carried no detrital fragments, but there was actually deposition of calcareous tufa; and this deposition was most rapid at points specially exposed to the violence of the waves.

Indeed, the agitation must be carried to the bottom in all cases where the depth operates as a condition in determining the magnitude of waves, for that determination can be assigned only to a resistance opposed by the bottom to the undulation of the water.

During the passage of a wave each particle of water affected by it rises and falls, and moves forward and backward, describing an orbit. If the passing wave is a swell, the orbit of the particle is closed,[8] and is either a circle or an ellipse; but in the case of a wind wave the orbit is not closed. The relative amounts of horizontal and vertical motion depend on the depth of the particle beneath the surface, and on the relation of the total depth of the water to the size of the wave. If the water is deep as compared to the wave-length, the horizontal and vertical movements are sensibly equal, and their amount diminishes rapidly from the surface downward. If the depth is small, the horizontal motion is greater than the vertical, but diminishes less rapidly with depth. Near the line of breakers, the vertical motion close to the bottom becomes inappreciable, while the horizontal oscillation is nearly as great as at the surface. This horizontal motion, affecting water which is at the same time under the influence of the undertow, gives to that current a pulsating character, and thus endows it with a higher transporting power than would pertain to its mean velocity. Near the breaker line, the oscillation communicated by the wave may even overcome and momentarily reverse the movement of the undertow. Inside the breaker line no oscillation proper is communicated. The broken wave crest, dashing forward, overcomes the undertow and throws it back; but the water returns without acceleration as a simple current descending a slope.

It should be explained that the increment given by pulsation to the transporting power of the undertow depends upon the general law that the transporting power of a current is an increasing geometric function of its velocity. Doubling the velocity of a current more than doubles the amount it can carry, and more than doubles the size of the particles it is able to move.

The transporting power of the undertow diminishes rapidly from the breaker line outward. That part of its power which depends on its mean velocity diminishes as the prism of the undertow increases; that part which depends on the rhythmic accelerations of velocity diminishes as the depth of water increases.

The pulsating current of the undertow has an erosive as well as a transporting function. It carries to and fro the detritus of the shore, and, dragging it over the bottom, continues downward the erosion initiated by the breakers. This downward erosion is the necessary concomitant of the shoreward progress of wave erosion; for if the land

[8] This is strictly true only while the swell traverses deep water. It is pointed out by Cialdi that in passing to shoal water the swell is converted into a wave of translation, and the particles no longer return to their points of starting.

were merely planed away to the level of the wave troughs, the incoming waves would break where shoal water was first reached and become ineffective at the water margin. In fact, this spending of the force of the waves where the water is so shallow as to induce them to break, increases at that point the erosive power by pulsation, and thus brings about an interdependence of parts. What may be called a normal profile of the submerged terrace is produced, the parts of which are adjusted to an harmonious interrelation. If some exceptional temporary condition produces abnormal wearing of the outer margin of the terrace, the greater depth of water at that point permits the incoming waves to pass with little impediment and perform their work of erosion upon portions nearer the shore, thus restoring the equilibrium. If exceptional resistance is opposed by the material at the water margin, erosion is there retarded until the submerged terrace has been so reduced as to permit the incoming waves to attack the land with a greater share of unexpended energy. Conversely, if there is a diminution of resistance at the water margin, so as to permit a rapid erosion, the landward recession of that margin causes it to be the less exposed to wave action. Thus the landward wear at the water margin and the downward wear in the several parts of the submerged plateau are adjusted to an interdependent relation.

THE SEA CLIFF.

Wave erosion, acting along a definite zone, may be rudely compared to the operation of a horizontal saw; but the upper wall of the saw cut, being without support, is broken away by its own weight and falls in fragments, leaving a cliff at the shoreward margin of the cut. This wave-wrought cliff requires a distinctive name to avoid confusion with cliffs of other origin, and might with propriety in this discussion be called a lake-cliff; but the phrase *sea-cliff* is so well established that it appears best to retain it.

One of the most noteworthy and constant characters of the sea-cliff is the horizontality of its base. The base being determined by wave erosion must always stand at about the level of the lake on which the waves are formed. The material of the cliff is the material of the land from which it is carved. Its declivity depends partly on the nature of that material and partly on the rate of erosion. If the material is unconsolidated the inclination cannot exceed the normal earth slope. If it is thoroughly indurated, the cliff may be vertical or even overhanging. If the rate of wave erosion is exceedingly rapid, the cliff is as steep as the material will permit; if the rate is slow, the inclination is diminished by the atmospheric waste of the cliff face.

Figure 1 represents a cliff on the shore of Great Salt Lake. The material in this case is arenaceous limestone. At the base of the cliff may be seen a portion of the accompanying wave-cut terrace, and the

foreground exhibits a portion of the accompanying beach. The large bowlders of the foreground have an independent origin, but the shingle

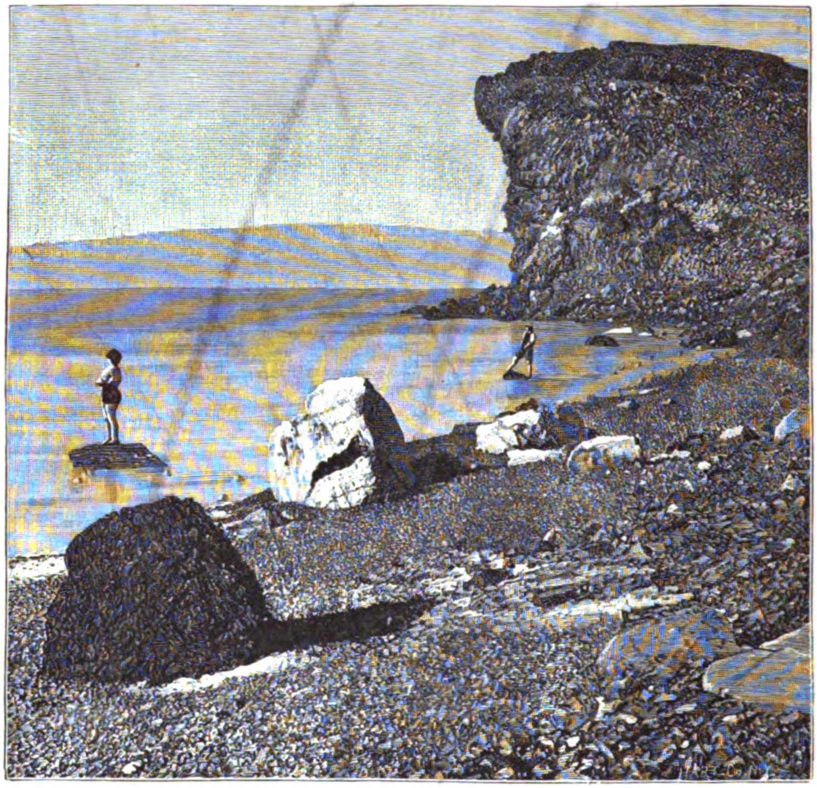


FIG. 1.—Sheep Rock, a sea-cliff on the shore of Great Salt Lake, near the Black Rock bathing resort.

and other material of the beach were derived from the erosion of the cliff and transported to their present position by the waves.

It will appear in the sequel that the distribution of sea-cliffs is somewhat peculiar, but this cannot be described until the process of littoral transportation has been explained.

THE WAVE-CUT TERRACE.

The submerged plateau whose area records the landward progress of littoral erosion, becomes a terrace after the formative lake has disappeared, and, as such, requires a distinctive name. It will be called the *wave-cut terrace.*

Its prime characteristics are, first, that it is associated with a cliff; second, that its upper margin, where it joins the cliff, is horizontal; and, third, that its surface has a gentle inclination away from the cliff. There

Fig. 1

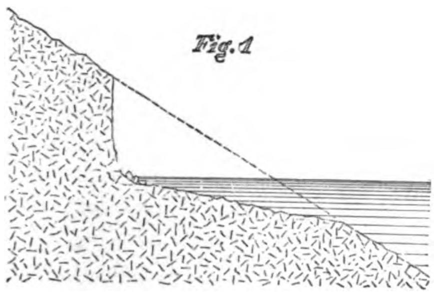


Fig. 2

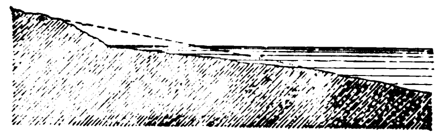


Fig. 3

Fig. 4

Fig. 5

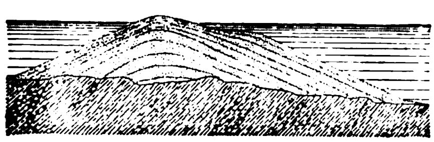


Fig. 6

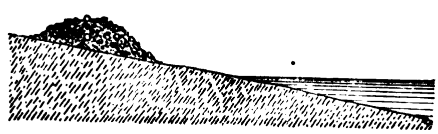
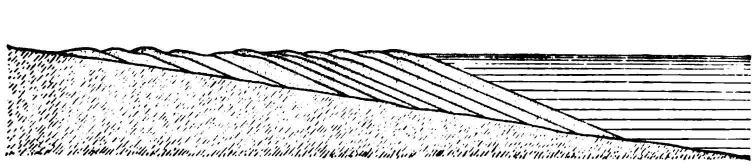


Fig. 7



IDEAL CROSS-SECTIONS OF SHORES.

is an exceptional case in which an island or a hill of the mainland has been completely pared away by wave action, so that no cliff remains as a companion for the wave-cut terrace; but this exception does not invalidate the rule. The lakeward inclination is somewhat variable, depending on the nature of the material and on the pristine acclivity of the land. It is greater where the material is loose than where it is coherent; and greater where the ratio of terrace width to cliff height is small. It is probably conditioned also by the direction of the current associated with the wind efficient in its production; but this has not been definitely ascertained.

The width of the terrace depends, of course, on the extent of the littoral erosion and is not assignable. Its relative width, in different parts of a given continuous coast, depends entirely upon the conditions determining the rapidity of erosion; and the discussion of these at this point would be premature.

Figure 1 of plate IV is an ideal section of a cliff and terrace carved from hard material. Figure 2 exhibits the characters of a cliff and terrace in soft material.

LITTORAL TRANSPORTATION.

The agent of littoral transportation is the joint action of waves and currents. Usually, and especially when the wind blows, the water adjacent to the shore is stirred by a gentle current flowing parallel to the water margin. This carries along the particles of detritus agitated by the waves. The waves and undertow move the shallow water near the shore rapidly to and fro, and in so doing momentarily lift some particles, and roll others forward and back. The particles thus wholly or partially sustained by the water are at the same moment carried in a direction parallel to the shore by the shore current. The shore current is nearly always exceedingly gentle and has of itself no power to move detritus.

When the play of the waves ceases, all shore action is arrested. When the play of the waves is unaccompanied by a current, shore action is nearly arrested but not absolutely. If the incoming waves move in a direction normal to the shore, the advance and recoil of the water move particles toward and from the shore, and effect no transfer in the direction of the shore; but if the incoming wave moves in an oblique direction the forward transfer of particles is in the direction of the wave, while the backward transfer, by means of the undertow, is sensibly normal to the shore, and there is thus a slow transportation along the shore. If there were no currents a great amount of transportation would undoubtedly be performed in this way, but it would be carried on at a slow rate. The transporting effect of waves alone is so slight

that only a gentle current in the opposite direction is necessary to counteract it. The concurrence of waves and currents is so general a phenomenon, and the ability of waves alone is so small, that the latter may be disregarded. The practical work of transportation is performed by the conjoint action of waves and shore currents.

In the ocean the causes of currents are various. Besides wind currents there are daily currents upon all coasts caused by tides, and it is maintained by some physicists that the great currents are wholly or partly due to the unequal heating of the water in different regions. But in lakes there are no appreciable tides, and currents due to unequal heating have never been discriminated. The motions of the water are controlled by the wind.

A l ng-continued wind in one direction produces a set of currents harmoniously adjusted to it. A change in the wind produces a change in the currents, but this adjustment is not instantaneous, and for a time there is lack of harmony. The strong winds, however, bring about an adjustment more rapidly than the gentle, and since it is to these that all important littoral work is ascribed, the waves and currents concerned in littoral transportation may be here regarded as depending on one and the same wind.

A wind blowing directly toward a shore may be conceived of as piling the superficial water against the shore, to be returned only by the undertow, but, in fact, so simple a result is rarely observed. Usually there is some obliquity of direction, in virtue of which the shoreward current is partially deflected, so as to produce as one of its effects a flow parallel to the shore, or a littoral current. The littoral current thus tends in a direction harmonious with the movement of the waves, passing to the right if the waves tend in that direction, to the left if the waves thus tend.

To this rule there is a noteworthy exception. The undertow is not the only return current. It frequently occurs that part of the water driven forward by the wind returns as a superficial current somewhat opposed in direction to the wind. If this current follows a shore it constitutes a littoral current whose tendency is opposed to that of the waves. Thus the littoral current may move to the right while the waves tend to the left and *vice versa*. In every such case the direction of transportation is the direction of the littoral current.

The waves and undertow accomplish a sorting of the detritus. The finer portion, being lifted up by the agitation of the waves, is held in suspension until carried outward to deep water by the undertow. The coarser portion, sinking to the bottom more rapidly, cannot be carried beyond the zone of agitation, and remains as a part of the shore. Only the latter is the subject of littoral transportation. It is called *shore drift*.

With the shifting of the wind the direction of the littoral current on any lake shore is occasionally, or it may be frequently, reversed, and the

... opposite direction is necessary to ... of waves and currents is so general ... as so small, that the ... work of transportation is performed ... currents.

... Besides wind currents ... all coasts caused by tides and it is ... the great currents are wholly ... of the water in different regions. ... tides and currents due to unequal ... The motions of the water are

... direction produces a set of currents. ... change in the wind produces a change ... is not instantaneous, and for a ... The strong winds, however, being about ... and since it is to these ... ascribed, the waves and currents ... may be here regarded ... depending

... a shore may be conceived of as piling ... shore, to be returned only by the under... is rarely observed. Usually there ... by virtue of which the shoreward current ... produce as one of its effects a flow ... littoral current. The littoral current ... with the movement of the waves, pass... in that direction ... the left if the

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SEA-CLIFF IN HARD SANDSTONE, WITH BEACH BEYOND. AU TRAIN ISLAND, LAKE SUPERIOR.

shore drift under its influence travels sometimes in one direction and sometimes in the other. In most localities it has a prevailing direction, not necessarily determined by the prevailing direction of the shore current, but by the direction of that shore current which accompanies the greatest waves. This is frequently but not always the direction also of the shore current accompanying the most violent storms.

The source of shore drift is two-fold. A large part is derived from the demolition of sea-cliffs, and is thus the product of littoral erosion. From every sea cliff a stream of shore drift may be seen to follow the coast in one direction or the other.

Another part is contributed by streams depositing at their mouths the heavy part of their detritus, and is more remotely derived from the erosion of the land. The smallest streams merely reinforce the trains of shore drift flowing from sea-cliffs, and their tribute usually cannot be discriminated. Larger streams furnish bodies of shore drift easily referred to their sources. Streams of the first magnitude, as will be explained farther on, overwhelm the shore drift and produce structures of an entirely different nature, known as deltas.

THE BEACH.

The zone occupied by the shore drift in transit is called the *beach*. Its lower margin is beneath the water, a little beyond the line where the great storm waves break. Its upper margin is usually a few feet above the level of still water. Its profile is steeper upon some shores than others, but has a general facies consonant with its wave-wrought origin. At each point in the profile the slope represents an equilibrium in transporting power between the inrushing breaker and the outflowing undertow. Where the undertow is relatively potent its efficiency is diminished by a low declivity. Where the inward dash is relatively potent the undertow is favored by a high declivity. The result is a sigmoid profile of gentle flexure, upwardly convex for a short space near its landward end, and concave beyond. (See Fig. 3, Plate IV.)

In horizontal contour the beach follows the original boundary between land and lake, but does not conform to its irregularities. Small indentations are filled by shore drift, and a smooth, sweeping outline is given to the water margin.

THE BARRIER.

Where the sublittoral bottom of the lake has an exceedingly gentle inclination the waves break at a considerable distance from the water margin. The most violent agitation of the water is along the line of breakers; and the shore drift, depending upon agitation for its transportation, follows the line of the breakers instead of the water margin. It is thus built into a continuous outlying ridge at some distance from the water's edge. It will be convenient to speak of this ridge as a *barrier*. (See Fig. 4, Plate IV.)

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9 Loc. cit., p.
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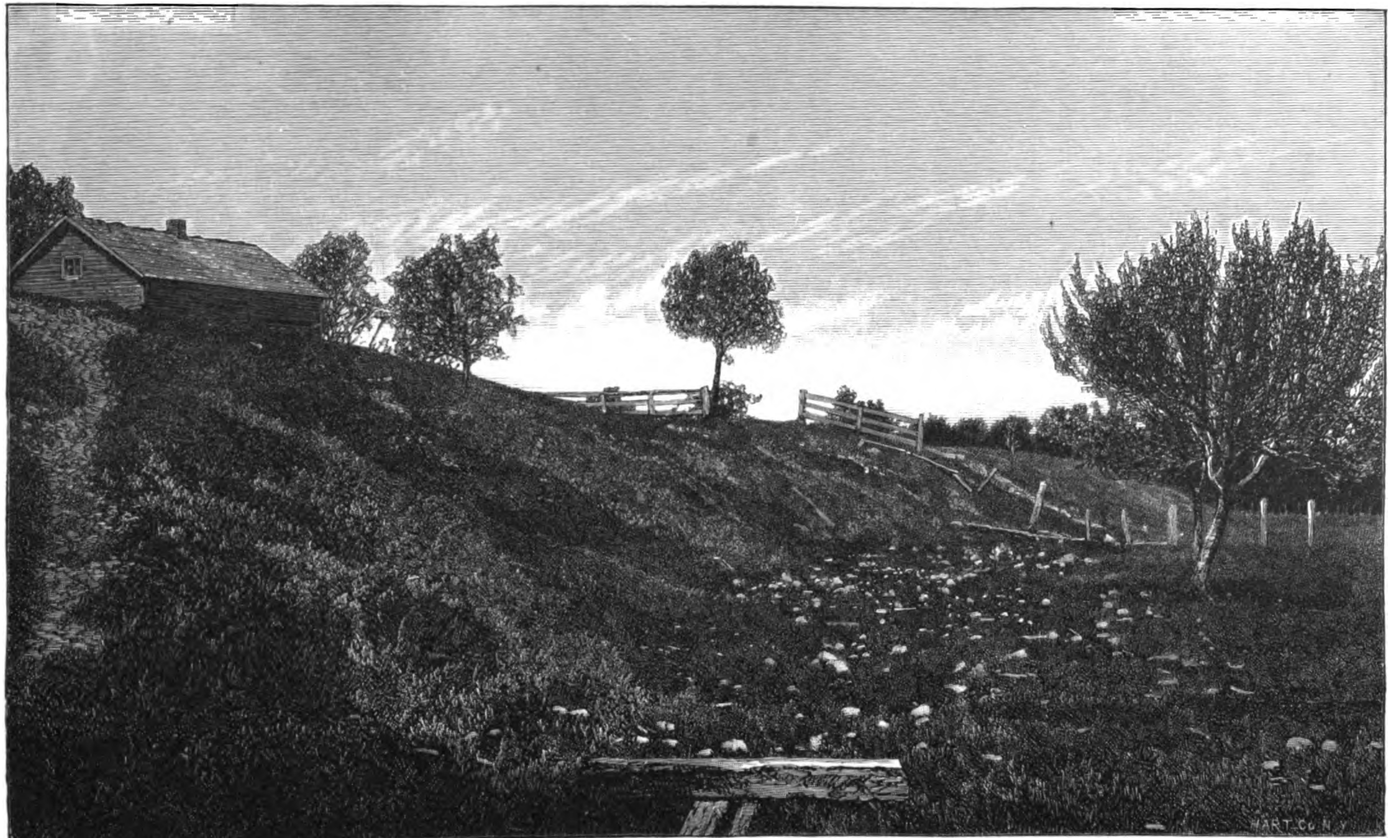

ANCIENT SEA-CLIFF IN BOULDER CLAY. SOUTH MANITOU ISLAND, LAKE MICHIGAN.

[illegible] of the beach. It is the road [illegible] and [illegible] itself composed of shore [illegible]. [illegible] crest [illegible] a few [illegible] of the waves.

[illegible] a strip of water is enclosed [illegible] converted into a marsh by the [illegible] vegetable matter, and eventually becomes [illegible] bridge over the interval between land and [illegible] into a [illegible] beach.

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[illegible] of these [illegible] depends in [illegible] a principle [illegible] on the one hand [illegible] that [illegible] be [illegible] of [illegible]. There are numerous geologic processes in [illegible] quantitative [illegible] causative factor [illegible] greater quan[illegible] of the effect. It is somewhat as though the effect was proportioned to an [illegible] power of the cause, but the relation is never so simple. [illegible], for example, the transportation of [illegible] by [illegible]. The variable cause is the volume of water; the [illegible] amount of geologic work done—the quantity of detritus [illegible] is related to the cause in three different ways: [illegible] water volume augments the velocity of flow, and with [illegible] the size of the maximum particle which can be

[illegible] Cabil[illegible] work is [illegible] waves, and that [illegible] shore [illegible] in the [illegible] is quantitatively [illegible] the [illegible] same winds which [illegible] waves [illegible]

ANCIENT SEA-CLIFF IN BOULDER CLAY. SOUTH MANITOU ISLAND, LAKE MICHIGAN.

moved increases rapidly. According to Hopkins, the size of the maximum fragment which can be moved varies as the sixth power of the velocity, or (roughly) as the $\frac{3}{2}$ power of the volume of water. Second, the increase of velocity enlarges the capacity of the water to transport detritus of a given character; that is, the per cent. of load to the unit of water is increased. Third, increase in the number of unit volumes of water increases the load *pro rata.* The summation of these three tendencies gives to the flooded stream a transporting power scarcely to be compared with that of the same stream at its low stage, and it gives to the exceptional flood a power greatly in excess of the normal or annual flood. Not only is it true that the work accomplished in a few days during the height of the chief flood of the year is greater than all that is accomplished during the remainder of the year, but it may even be true that the effect of the maximum flood of the decade or generation or century surpasses the combined effects of all minor floods. It follows that the dimensions of the channel are established by the great flood and adjusted to its needs.

In littoral transportation the great storm bears the same relation to the minor storm and to the fair weather breeze. The waves created by the great storm not only lift more detritus from each unit of the littoral zone, but they act upon a broader zone, and they are competent to move larger masses. The currents which accompany them are correspondingly rapid, and carry forward the augmented shore drift at an accelerated rate. It follows that the habit of the shore, including not only the maximum height of the beach line and the height of its profile, but the dimensions of the wave-cut terrace and of various other wave products presently to be described, is determined by and adjusted to the great storm.

It should be said by way of qualification that the low tide stream and the breeze-lifted wave have a definite though subordinate influence on the topographic configuration. After the great flood has passed by, the shrunken stream works over the finer débris in the bed of the great channel, and by removing at one place and adding at another shapes a small channel adjusted to its volume. After the great storm has passed from the lake and the storm swell has subsided, the smaller waves of fair weather construct a miniature beach profile adapted to their size, superimposing it on the greater profile. This is done by excavating shore drift along a narrow zone under water and throwing it up in a narrow ridge above the still-water level. Thus, as early perceived by Beaumont,[10] it is only for a short time immediately after the passage of the great storm that the beach profile is a simple curve. It comes afterward to be interrupted by a series of superimposed ridges produced by storms of different magnitude.

Reverting now to the special conditions controlling the profiles of beach or barrier at an individual locality, it is evident that the chief of

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[10] Loc. cit., p. 226, Plate IV.

[illegible] waves breaking [illegible]. The [illegible] force of the wind act on [illegible] and [illegible] from the opposite [illegible] [illegible] to the square root of [illegible] provided there are no [illegible] for a given force of wind [illegible] command [illegible] their incidence at the [illegible]

[illegible] configuration of the bottom. Where [illegible] undertow rapidly returns the water [illegible] there is little accumulation against [illegible] depth is small the wind piles the [illegible] all shore features at a relatively

LITTORAL DEPOSITION.

[illegible] deposited by shore processes is, first, shore drift; and, [illegible] or the detritus delivered at the shore by tributary [illegible] depth of water is in each case the condition of [illegible]. The structures produced by the deposit of shore [illegible] somewhat varied, have certain common features. They [illegible] the generic title of *embankments*. The structures [illegible] the deposit of stream drift are *deltas*.

EMBANKMENTS.

[illegible] occupying the zone of the shore drift and acting as [illegible] of littoral transportation has been described as slow, but it [illegible] connected with a movement that is relatively rapid. [illegible] water, which may be called the off-shore current, occupies deeper [illegible] and is less impeded by friction. It may in some sense be said to [illegible] the littoral current along with it. The momentum of the off-shore current does not permit it to follow the sinuosities of the water margin. [illegible] it sweeps from point to point, carrying the littoral current with it. There is even a tendency to generate eddies or return currents in embayments of the coast. The off-shore current is moreover controlled in part by the configuration of the bottom and by the necessity of a return current. The littoral current, being controlled in large part by the movements of the off-shore current, separates from the water margin in three ways: first, it continues its direction unchanged at points where [illegible] shore line turns landward, as at the entrances of bays; second, it

BEACH OF LIMESTONE PEBBLES. MACKINAW ISLAND, MICHIGAN.

these is the magnitude of the largest waves breaking there. The size of the waves at each locality depends on the force of the wind and on its direction. A wind blowing from the shore lakeward produces no waves on that shore. A wind blowing from the opposite shore produces waves whose height is approximately proportional to the square root of the distance through which they are propagated, provided there are no shoals to check their augmentation. For a given force of wind the greatest waves are produced when the direction is such as to command the broadest sweep of water before their incidence at the particular spot.

A second factor is found in the configuration of the bottom. Where the off-shore depth is great the undertow rapidly returns the water driven forward by the wind, and there is little accumulation against the shore; but where the off-shore depth is small the wind piles the water against the shore, and produces all shore features at a relatively high level.

LITTORAL DEPOSITION.

The material deposited by shore processes is, first, shore drift; and, second, stream drift or the detritus delivered at the shore by tributary streams. Increasing depth of water is in each case the condition of littoral deposition. The structures produced by the deposit of shore drift, although somewhat varied, have certain common features. They will be treated under the generic title of *embankments*. The structures produced by the deposit of stream drift are *deltas*.

EMBANKMENTS.

The current occupying the zone of the shore drift and acting as the coagent of littoral transportation has been described as slow, but it is inseparably connected with a movement that is relatively rapid. This latter, which may be called the off-shore current, occupies deeper water and is less impeded by friction. It may in some sense be said to drag the littoral current along with it. The momentum of the off-shore current does not permit it to follow the sinuosities of the water margin, and it sweeps from point to point, carrying the littoral current with it. There is even a tendency to generate eddies or return currents in embayments of the coast. The off-shore current is moreover controlled in part by the configuration of the bottom and by the necessity of a return current. The littoral current, being controlled in large part by the movements of the off-shore current, separates from the water margin in three ways: first, it continues its direction unchanged at points where the shore line turns landward, as at the entrances of bays; second, it

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BEACH OF LIMESTONE PEBBLES. MACKINAW ISLAND, MICHIGAN.

sometimes turns from the land as a surface current; third, it sometimes descends and leaves the water margin as a bottom current.

In each of these three cases deposition of shore drift takes place by reason of the divorce of shore currents and wave action. The depth to which wave agitation sufficient for the transportation of shore drift extends is small, and when the littoral current by leaving the shore passes into deeper waters the shore drift, unable to follow, is thrown down.

When the current holds its direction and the shore line diverges, the embankment takes the form of a *spit*, a *hook*, a *bar*, or a *loop*. When the shore line holds its course and the current diverges, whether superficially or by descent, the embankment usually takes the form of a *terrace.*

THE SPIT.

When a coast line followed by a littoral current turns abruptly landward, as at the entrance of a bay, the current does not turn with it, but holds its course and passes from shallow to deeper water. The water between the diverging current and coast is relatively still, although there is communicated to the portion adjacent to the current a slow motion in the same direction. The waves are propagated indifferently through the flowing and the standing water, and reach the coast at all points. The shore drift cannot follow the deflected coast line, because the waves that beat against it are unaccompanied by a littoral current. It cannot follow the littoral current into deep water, because at the bottom of the deep water there is not sufficient agitation to move it. It therefore stops. But the supply of shore drift brought to this point by the littoral current does not cease, and the necessary result is accumulation. The particles are carried forward to the edge of the deep water and there let fall.

In this way an embankment is constructed, and so far as it is built it serves as a road for the transportation of more shore drift. The direction in which it is built is that of the littoral current. It takes the form of a ridge following the boundary between the current and the still water. Its initial height brings it just near enough to the surface of the water to enable the wave agitation to move the particles of which it is constructed, and it is narrow; but these characters are not long maintained. The causes which lead to the construction of the beach and the barrier are here equally efficient, and cause the embankment to grow in breadth and in height until the cross-profile of its upper surface is identical with that of the beach.

The history of its growth is readily deduced from the configuration of its terminus, for the process of growth is there in progress. If the material is coarse the distal portion is very slightly submerged, and is terminated in the direction of growth by a steep slope, the subaqueous "earth-slope" of the particular material. If the material is

fine the distal portion is more deeply submerged, and is not so abruptly terminated. The portion above water is usually narrow throughout, and terminates without reaching the extremity of the embankment. It is flanked on the windward side by a submerged plateau, at the outer edge of which the descent is somewhat steep. The profile of the plateau is that normal to the beach, and its contours are confluent with those of the beach or barrier on the main shore. Toward the end of the embankment its width diminishes, its outer and limiting contour turning toward the crest line of the spit and finally joining it at the submerged extremity.

The process of construction is similar to that of a railroad embankment the material for which is derived from an adjacent cutting, carted forward along the crest of the embankment and dumped off at the end; and the symmetry of form is often more perfect than the railway engineer ever accomplishes. The resemblance to railway structures is very striking in the case of the shores of extinct lakes.

As the embankment is carried forward and completed, contact between the current and the inshore water is at first obstructed and finally cut off, so that there is practically no communication of movement from one to the other at the extremity of the spit. At the point of construction the moving and the standing water are sharply differentiated, and there is hence no uncertainty as to the direction of construction. The spit not only follows the line between the current and still water, but aids in giving definition to that line, and eventually walls in the current by contours adjusted to its natural flow.

THE BAR.

If the current determining the formation of a spit again touches the shore, the construction of the embankment is continued until it spans the entire interval. So long as one end remains free the vernacular of the coast calls it a *spit;* but when it is completed it becomes a *bar.* An ideal cross-section of a completed embankment appears as Fig. 5, plate IV.

The bar has all the characters of the spit except those of the terminal end. Its cross-profile shows a plateau bounded on either hand by a steep slope. The surface of the plateau is not level, but has the beach profile, is slightly submerged on the windward side and rises somewhat above the ordinary water level at the leeward margin. At each end it is continuous with a beach or barrier. It receives shore drift at one end and delivers it at the other.

The bar may connect an island with the shore or with another island, or it may connect two portions of the same shore. In the last case it crosses the mouth either of a bay or of a river. If maintained entire across the entrance to a bay it converts the water between it and the shore into a lagoon. At the mouth of a river its maintenance is antagonized by the outflowing current, and if its integrity is established

at all it is only on rare occasions and for a short time. That is to say, its full height is not maintained; there is no continuous exposed ridge. The shore drift is, however, thrown into the river current, and unless that current is sufficient to sweep it into deep water a submerged bar is thrown across it, and maintains itself as a partial obstruction to the flow. The site of this submerged bar is usually also the point at which the current of the stream, meeting the standing water of the lake, loses its velocity and deposits the coarser part of its load of detritus. If the contribution of river drift greatly exceeds that of shore drift, a delta is formed at the river mouth, and this, by changing the configuration of the coast, modifies the littoral current and usually determines the shore drift to some other course. If the contribution of river drift is comparatively small it becomes a simple addition to the shore drift, and does not interrupt the continuity of its transportation. The bars at the mouths of small streams are constituted chiefly of shore drift, and all their characters are determined by their origin. The bars at the mouths of large streams are constituted chiefly of stream drift, and belong to the phenomena of deltas.

On a preceding page the fact was noted that the horizontal contours of a beach are more regular than those of the original surface against which it rests, small depressions being filled. It is now evident that the process of filling these is identical with that of bar construction. There is no trenchant line of demarkation between the beach and the bar. Each is a carrier of shore drift, and each employs its first load in the construction of a suitable road.

Plate VIII represents a portion of the east shore of Lake Michigan as seen from the hill back of Empire Bluffs. In the extreme distance at the left stand the Sleeping Bear Bluffs, and somewhat nearer on the shore, is a timbered hill, the lakeward face of which is likewise a sea-cliff. A bar connects the latter with the land in the foreground and divides the lagoon at the right from the lake at the left. The symmetry of the bar is marred by the formation of dunes, the lighter portion of the shore-drift being taken up by the wind and carried toward the right so as to initiate the filling of the lagoon.

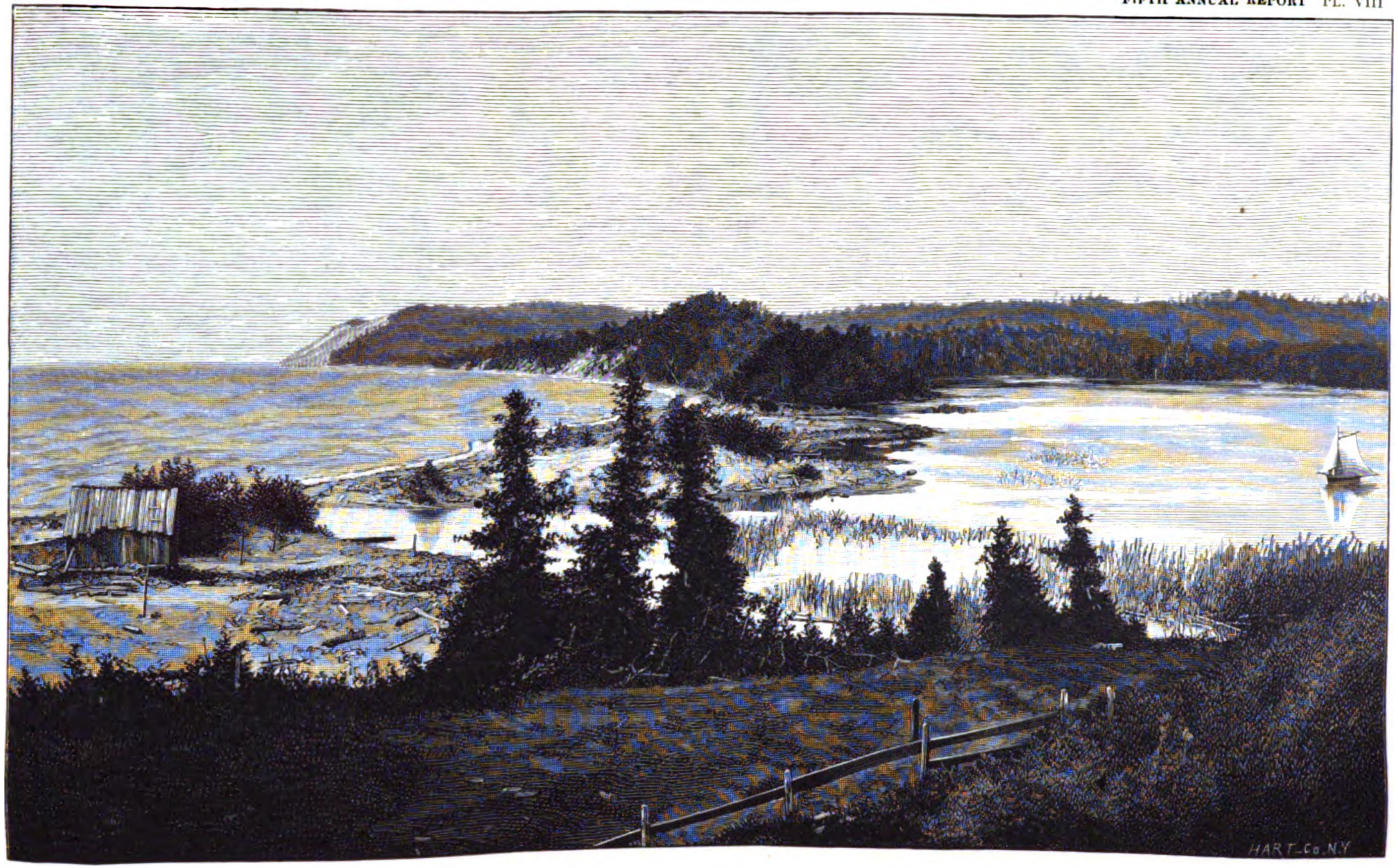
Figure 2 is copied from the U. S. Engineer map of a portion of the south shore of Lake Ontario west of the mouth of the Genesee River. The original contour of the shore was there irregular, consisting of a series of salient and re-entrant angles. The waves have truncated some of the salients and have united them all by a continuous bar, behind which a series of bays or ponds is inclosed. The movement of the shore drift is in this case from northwest to southeast, and the principal source of the material is a point of land at the extreme west, where a low cliff shows that the land is being eaten by the waves.

The map in figure 3 is likewise copied from one of the sheets published by the U. S. Engineers, and represents the bars at the head of Lake Superior. These illustrate several elements of the preceding

discussion. In the first place they are not formed by the predominant winds, but by those which bring the greatest waves. The predominant winds are westerly, and produce no waves on this coast. The shore drift is derived from the south coast, and its motion is first westerly

FIG. 2.—Map of Braddock's Bay and vicinity, Lake Ontario.

FIG. 3.—Map of the head of Lake Superior.



BAR JOINING EMPIRE AND SLEEPING-BEAR BLUFFS, LAKE MICHIGAN.

and then northerly. Two bars are exhibited, the western of which is now protected from the lake waves, and must have been completed before the eastern was begun. The *locus* of deposition of shore drift was probably shifted from the western to the eastern by reason of the shallowing of the head of the lake. The converging shores should theoretically produce during easterly storms a powerful undertow, by which a large share of the shore drift would be carried lakeward and distributed over the bottom. The manner in which the bars terminate against the northern shore without inflection is explicable likewise by the theory of a strong undertow. If the return current were superficial the bars would be curved at their junctions with both shores.

The view in plate XI represents a portion of the Bonneville shore line. The mountain portrayed is a spur on the west side of the Oquirrh range, between Tooele and Stockton. The town of Stockton appears at the right. The plain at the left was the bed of the lake. The storm waves, moving from left to right, carved the sea cliff which appears at the base of the mountain at the left, and drifting the material toward the right built it into a great spit and a greater bar. The end of the spit is close to the town of Stockton. The bar, which lies slightly lower, having been formed by the lake at a lower stage of its water, sweeps in a broad curve across the valley to the spur on the opposite side, where the artist stood in making the sketch. Besides exhibiting the relation of embankments to sea cliffs, the view illustrates well the contrast between the topographic features of the land and of the shore.

THE HOOK.

The line of direction followed by the spit is usually straight, or has a slight concavity toward the lake. This form is a function of the littoral current, to which it owes origin. But that current is not perpetual; it exists only during the continuance of certain determining winds. Other winds, though feebler or accompanied by smaller waves, nevertheless have systems of currents, and these latter currents sometimes modify the form of the spit. Winds which simply reverse the direction of the littoral current retard the construction of the embankment without otherwise affecting it; but a current is sometimes made to flow past the end of the spit in a direction making a high angle with its axis, and such a current modifies its form. It cuts away a portion of the extremity and rebuilds the material in a smaller spit joining the main one at an angle. If this smaller spit extends lakeward it is demolished by the next storm; but if it extends landward its position is sheltered, and it remains a permanent feature. It not infrequently happens that such accessory spits are formed at intervals during the construction of a long embankment, and are preserved as a series of short branches on the lee side.

It may occur also that a spit at a certain stage of its growth becomes especially subject to some conflicting current, so that its normal growth

ceases, and all the shore drift transported along it goes to the construction of the branch. The bent embankment thus produced is called a *hook.*

Plate IX represents a recurved spit on the shore of Lake Michigan, as seen from a neighboring bluff. The general direction of its construction is from left to right, but storms from the right have from time to time turned its end toward the land and the successive recurvements are clearly discernible near the apex. The last of these is the greatest; and it is possible that the spit has acquired permanently the form of a hook.

The currents efficient in the formation of a hook do not co-operate simultaneously, but exercise their functions in alternation. The one, during the prevalence of certain winds, brings the shore drift to the angle and accumulates it there; the other, during the prevalence of other winds, demolishes the new structure and redeposits the material upon the other limb of the hook.

In case the land on which it is based is a slender peninsula or a small island, past which the currents incited by various winds sweep with little modification of direction by the local configuration, the hook no longer has the sharp angle due to the action of two currents only, but receives a curved form.

Hooks are of comparatively rare occurrence on lake shores, but abound at the mouths of marine estuaries, where littoral and tidal currents conflict.

THE LOOP.

Just as the spit by advancing until it rejoins the shore becomes a bar, so the completed hook may with propriety be called a *loop* or a *looped bar.* There is, however, a somewhat different feature to which the name is more strikingly applicable. A small island standing near the main-land is usually furnished on each side with a spit streaming toward the land. These spits are composed of detritus eroded from the lakeward face of the island, against which beat the waves generated through the broad expanse. The currents accompanying the waves are not uniform in direction, but vary with the wind through a wide angle; and the spits in sympathy with the varying direction of currents are curved inward toward the island. If their extremities coalesce, they constitute together a perfect loop, resembling, when mapped, a festoon pendant from the sides of the island.

Such a loop in the fossil condition, that is, when preserved as a vestige of the shore of an extinct lake, has the form of a crater rim, the basin of the original lagoon remaining as an undrained hollow. The accompanying illustration (Plate X) represents an island of Lake Bonneville standing on the desert near what is known as the "Old River Bed." The nucleus of solid rock was in this instance nearly demolished before the work of the waves was arrested by the lowering of the water.

DUTCH POINT; A RECURVED SPIT. GRAND TRAVERSE BAY, LAKE MICHIGAN.

CUP-BUTTE, A VESTIGE OF THE BONNEVILLE SHORE-LINE.

THE WAVE-BUILT TERRACE.

It has already been pointed out that when a separation of a littoral current from the coast line is brought about by a divergence of the current rather than of the coast line there are two cases, in the first of which the current continues at the surface, while in the second it dives beneath the surface. It is now necessary to make a further distinction. The current departing from the shore, but remaining at the surface, may continue with its original velocity or it may assume a greater cross-section and a diminished velocity. In the first case the shore drift is built into a spit or other linear embankment. In the second case it is built into a terrace. The quantity of shore drift moved depends on the magnitude of the waves; but the speed of transit depends on the velocity of the current, and wherever that velocity diminishes, the accession of shore drift must exceed the transmission, causing accumulation to take place. This accumulation occurs, not at the end of the beach, but on its face, carrying its entire profile lakeward and producing by the expansion of its crest a tract of new-made land. If afterward, as in the case of an extinct lake, the water disappears, the new-made land has the character of a terrace. A current which leaves the shore by descending, practically produces at the shore a diminution of flow, and the resulting embankment is nearly identical with that of a slackening superficial current.

The wave-built terrace is distinct from the wave-cut terrace in that it is a work of construction, being composed entirely of shore drift, while the wave-cut terrace is the result of excavation, and consists of the pre-existent terrane of the locality.

The surface of the wave-built terrace, considered in its *ensemble*, is level, but in detail it is uneven, consisting of parallel ridges usually curved. Each of these is referable to some exceptional storm, the waves of which threw the shore drift to an unusual height. (See Fig. 7, Plate IV.)

Where the shore drift consists wholly or in large part of sand, and the prevailing winds are toward the shore, the wave-built terrace gives origin to dunes, which are apt to mask its normal ribbed structure.

The locality most favorable for the formation of a wave-built terrace is the head of a triangular bay, up which the waves from a large body of water are rolled without obstruction. The wind sweeping up such a bay carries the surface of the water before it, and the only return current is an undertow originating near the head of the bay. The superficial advance of the water constitutes on each shore a littoral current conveying shore drift toward the head of the bay, and as these littoral currents are diminished and finally entirely dissipated by absorption in the undertow, the shore drift taken up along the sides of the bay is deposited. If the head of the bay is acute the first embankment built is a curved bar tangent to the sides and concave toward the open water. To the face of this successive additions are made, and a terrace

is gradually produced, the component ridges of which are approximately parallel. The sharpest curvature is at the extreme head of the now restricted bay, and the type of curve is probably parabolic.

The converging currents of such a bay give rise to an undertow which is of exceptional velocity, so that it transports with it not only the finest detritus but also coarser matter, such as elsewhere is usually retained in the zone of wave action. In effect there is a resorting of the material. The shore drift which has traveled along the sides of the bay toward its head, is divided into two portions, the finer of which passes out with the reinforced undertow, while the coarser alone is built into the terrace.

THE V-TERRACE AND V-BAR.

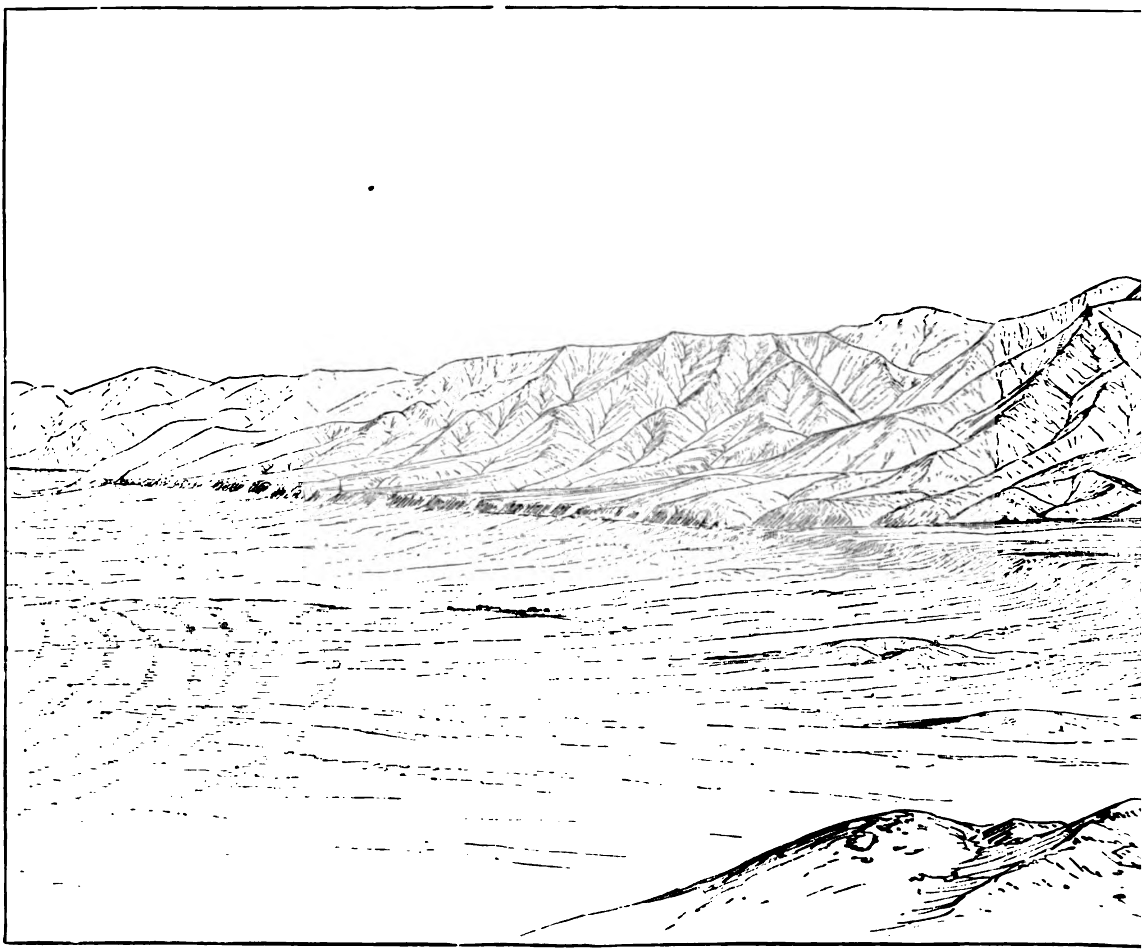
It remains to describe a type of terrace for which no satisfactory explanation has been reached. The shores of the ancient Quaternary lakes afford numerous examples, but those of recent lakes are nearly devoid of them, and the writer has never had opportunity to examine one in process of formation. They are triangular in ground plan, and would claim the title of delta were it not preoccupied, for they simulate the Greek letter more strikingly than do the river-mouth structures. They are built against coasts of even outline, usually, but not always, upon slight salients, and they occur most frequently in the long, narrow arms of old lakes.

One side of the triangle rests against the land and the opposite angle points toward the open water. The free sides meet the land with short curves of adjustment, and appear otherwise to be normally straight, although they exhibit convex, concave, and sigmoid flexures. The growth is by additions to one or both of the free sides; and the nucleus appears always to have been a miniature triangular terrace, closely resembling the final structure in shape. In the Bonneville examples the lakeward slope of the terrace is usually very steep down to the line where it joins the pre-existent slope of the bottom.

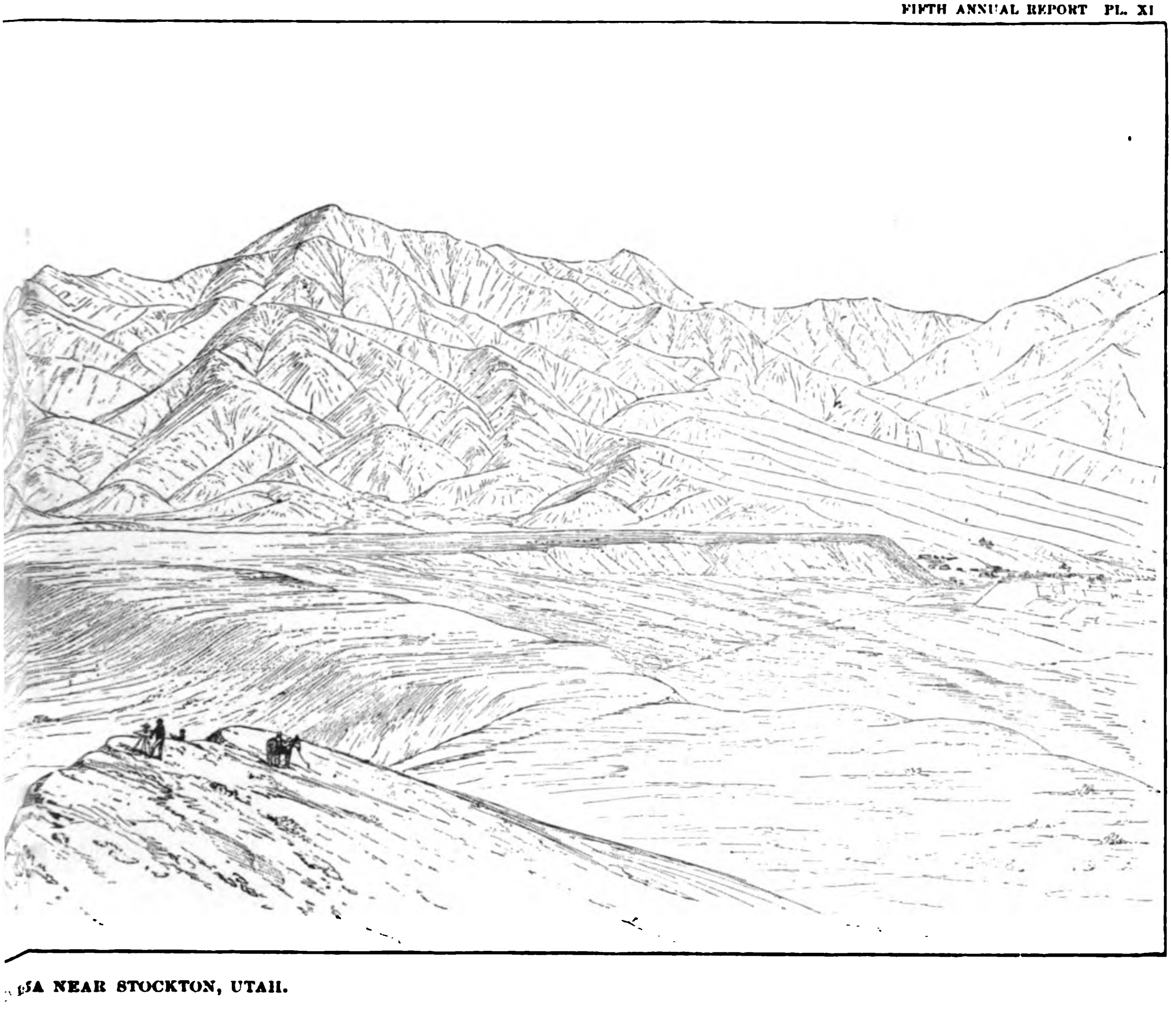
There seems no reason to doubt that these embankments, like the others, were built by currents and waves, and such being the case the formative currents must have diverged from the shore at one or both the landward angles of the terrace, but the condition determining this divergence does not appear.

In some cases the two margins appear to have been determined by currents approaching the terrace (doubtless at different times) from opposite directions; and then the terrace margins are concave outward, and their confluence is prolonged in a more or less irregular point. In most cases, however, the shore drift appears to have been carried by one current from the mainland along one margin of the terrace to the apex, and by another current along the remaining side of the terrace back to the main-land. The contours are then either straight or convex.

In Lake Bonneville it happened that after the best defined of these terraces had attained nearly their final width the lake increased in size, so



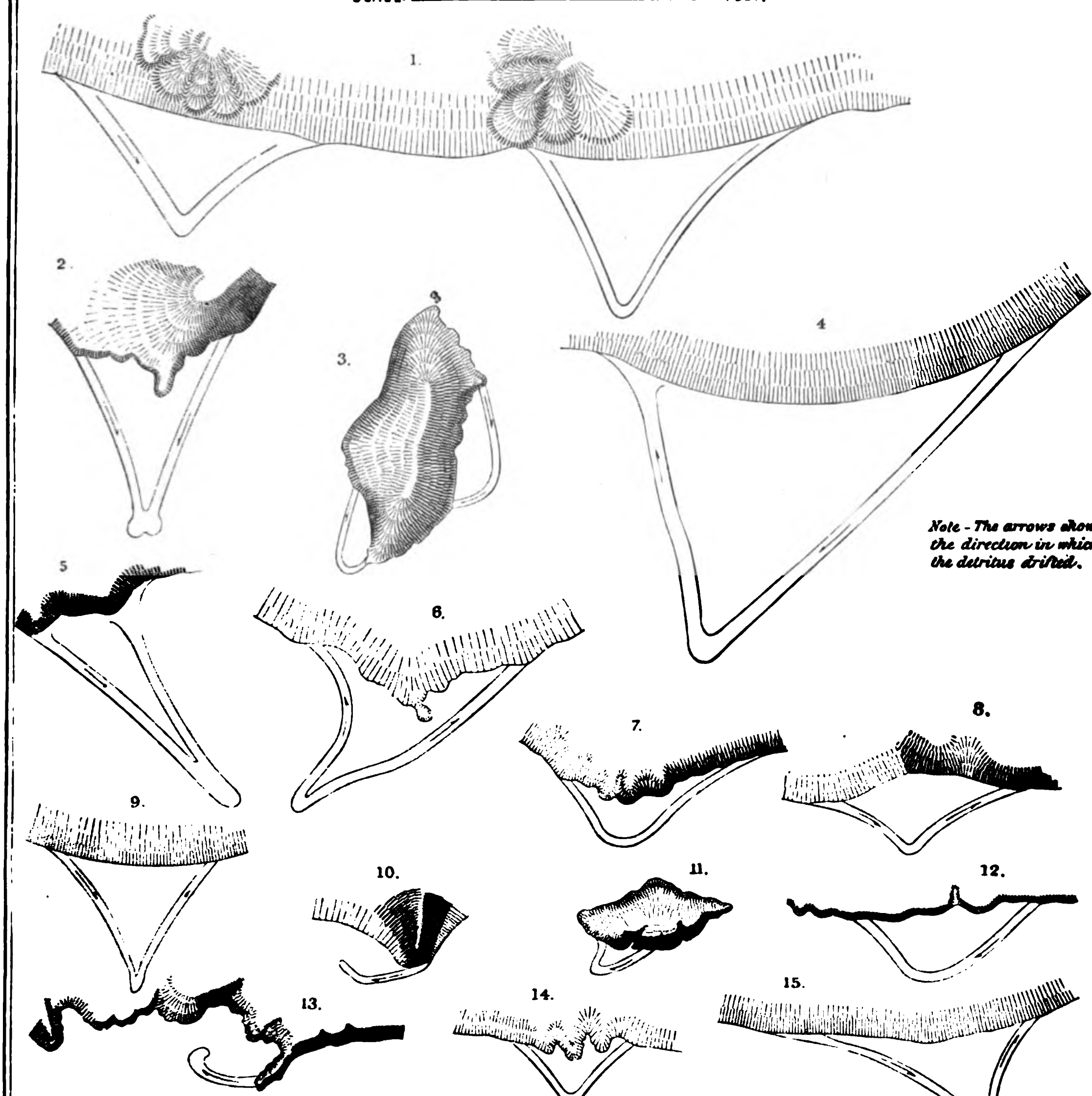
ANCIENT SHORE PHENOM



ESA NEAR STOCKTON, UTAH.

PLATS OF LOOPED AND V-SHAPED EMBANKMENTS, OBSERVED ON THE SHORES OF LAKE BONNEVILLE.

SCALE: 4000 FEET.



1, Salt Marsh, Snake Valley.
2, 11, East Base of Beaver Creek Range.
3, Reservoir Butte, Old River Bed.
4, Snowplow.
5. Point of the Mountain.
6, East Base, Deep Cr Mts
7, 14, " side of Old River Bed.
8, 9, 15, West Base of Frisco Mountain.
10, 12 Preuss Valley, near Wa-wa Spring.
13 Near Stockton.

that they were immersed beneath a few feet of water. While the lake stood at the higher level, additions were made to the terraces by the building of linear embankments at their outer margins. These were carried to the water surface, and a triangular lagoon was imprisoned at each locality. The sites of these lagoons are now represented by flat triangular basins, each walled in by a bar bent in the form of a **V**. These bars were at first observed without a clear conception of the terrace on which they were founded, and the name **V**-*bar* was applied. The **V**-bar, while a conspicuous feature of the Bonneville shores, is not believed to be a normal feature of lakes maintaining a constant level.

DRIFTING SAND: DUNES

The dune is not an essential shore feature, but it is an accessory of frequent occurrence.

Dunes are formed wherever the wind drifts sand across the land. The conditions essential to their production are wind, a supply of sand, and sterility or the absence of a protective vegetable growth. In arid regions sterility is afforded by the climatic conditions, and the sand furnished by river bars laid bare at low water, and by the disintegration of sand rocks, is taken up by the wind and built into dunes; but where rain is abundant, accumulations of such sort are protected by vegetation, and the only sources of supply are shores either modern or ancient.

Shore drift nearly always contains some sand and is frequently composed exclusively thereof. The undertow carries off the clay which might otherwise hold the sand particles together and prevent their removal by the wind; and pebbles and bowlders, which, by their superior weight oppose wind action, are less able to withstand the attrition of littoral transportation, and disappear by disintegration from any train of shore drift which travels a considerable distance. Embankments are therefore apt to be composed largely of sand; and the crests of embankments, being exposed to the air during the intervals between great storms, yield dry sand to the gentler winds.

The sand drifted from the crests of free embankments, such as barriers, spits, and bars, quickly reaches the water on one side or the other. What is blown to the lakeward side falls within the zone of wave action, and is again worked over as shore drift. What is blown to the landward side extends the area of the embankment, correspondingly encroaching on the lagoon or bay.

Sand blown from the crests of embankments resting against the land, such as beaches and terraces, will spread over the land if the prevailing wind is favorable. In cases where the prevailing wind is toward the lake the general movement of sand is, of course, in that direction, and it is merely returned to the zone of the waves and readded to the shore drift; but where the prevailing winds are toward the land, dunes are formed and slowly rolled forward by the wind. The supply of dry sand

SPIT OF SHINGLE. AU TRAIN ISLAND, LAKE SUPERIOR.

III.—THE DISTRIBUTION OF WAVE-WROUGHT SHORE FEATURES.

Upon every coast there are certain tracts undergoing erosion, certain others receive the products of erosion, and the intervals are occupied by the structures peculiar to transportation. Let us now inquire what are the conditions determining these three phases of shore shaping.

It will be convenient to consider first the conditions of transportation. In order that a particular portion of shore shall be the scene of littoral transportation, it is essential, first, that there be a supply of shore drift; second, that there be shore action by waves and currents; and in order that the local process be transportation simply, and involve neither erosion nor deposition, a certain equilibrium must exist between the quantity of the shore drift on the one hand and the power of the waves and currents on the other. On the whole this equilibrium is a delicate one, but within certain narrow limits it is stable. That is to say, there are certain slight variations of the individual conditions of equilibrium which disturb the equilibrium only in a manner tending to its immediate readjustment. For example, if the shore drift receives locally a small increment from stream drift, this increment, by adding to the shore contour, encroaches on the margin of the littoral current and produces a local acceleration, which acceleration leads to the removal of the obstruction. Similarly, if from some temporary cause there is a local defect of shore drift the resulting indentation of the shore contour slackens the littoral current and causes deposition, whereby the equilibrium is restored. Or if the force of the waves is at some point broken by a temporary obstruction outside the line of breakers, as for example by a wreck, the local diminution of wave agitation produces an accumulation of shore drift whereby the littoral current is narrowed and thus accelerated until an adjustment is reached.

Outside the limits thus indicated everything which disturbs the adjustment between quantity of shore-drift and capacity of shore agents leads either to progressive local erosion or else to progressive local deposition. The stretches of coast which either lose ground or gain are decidedly in excess of those which merely hold their own.

An excessive supply of shore drift over and above what the associated current and waves are competent to transport leads to deposition. This occurs where a stream of some magnitude adds its quota of débris. A moderate excess of this nature is disposed of by the formation of a wave-built terrace on the lee side of the mouth of the stream, that is, on the side toward which flows the littoral current accompanying the

greatest waves. A great excess leads to the formation of a delta, in which the stream itself is the constructing agent and the influence of waves is subordinate.

On the other hand, there is a constant loss of shore drift by attrition, the particles in transit being gradually reduced in size until they are removed from the littoral zone by the undertow. As a result of the defect thus occasioned, a part of the energy of the waves is expended on the subjacent terrane, and the work of transportation is locally accompanied by a sufficient amount of erosion to replenish the wasting shore drift. For the maintenance of a continuous beach in a permanent position, it appears to be necessary that small streams shall contribute enough débris to compensate for the waste by attrition.

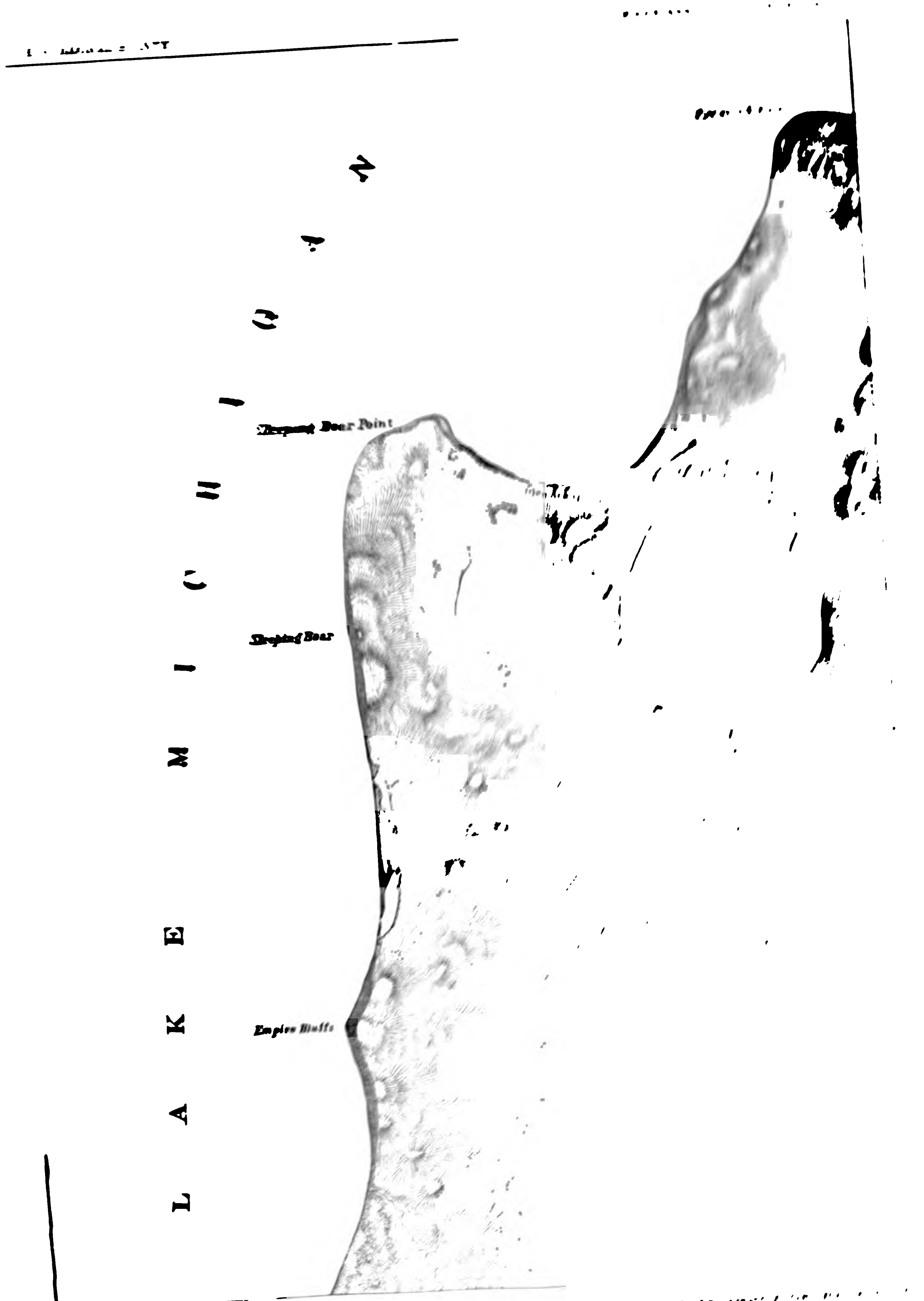
Theoretically, transportation must be exchanged for erosion wherever there is a local increase in the magnitude of waves, and for deposition where there is a local decrease of waves; but practically the proportions of waves are so closely associated with the velocities of the accompanying currents that their effects have not been distinguished.

The factor which most frequently, by its variation, disturbs the equilibrium of shore action is the littoral current. It has already been pointed out that wherever it leaves the shore, shore drift is deposited; and it is equally true that wherever it comes into existence by the impinging of an open water current on the shore, shore drift is taken up and the terrane is eroded. It has been shown also that the retardation of the littoral current produces deposition, and it is equally true that its acceleration causes erosion. Every variation, therefore, in the direction or velocity of the current at the shore has a definite effect in the determination of the local shore process.

Re-entrant angles of the coast are always, and re-entrant curves are usually, places of deposition. The reason for this is twofold: first, currents which follow the shore move with diminished velocity in passing re-entrants; second, currents directed toward the shore escape from re-entrants only by undertow, and, as heretofore explained, build terraces at the heads of the embayments.

Salient angles are usually eroded, and salient curves nearly always, the reasons being, first, that a current following the shore is relatively swift opposite a salient, and, second, that a current directed toward the shore is apt to be divided by a salient, its halves being converted into littoral currents transporting shore drift in opposite directions *away* from the salient.

Some salient angles, on the contrary, grow by deposition. This occurs where the most important current approaches by following the shore and is thrown off to deep water by a salient. The most notable instances are found on the sides of narrow lakes or arms of lakes, in which case currents approaching from the direction of the length are accompanied by greater waves than those blown from the direction of the opposite shore, and therefore dominate in the determination of the local action.



MAP OF A PORTION OF THE SHORE OF LAKE MICHIGAN, ILLUSTRATING ... TO SIMPLIFY SHORE CONTOURS

It thus appears that there is a general tendency to the erosion of salients and the filling of embayments, or to the simplification of coast outlines. This tendency is illustrated not only by the shores of all lakes, but by the coasts of all oceans. In the latter case it is slightly diminished by the action of tides, which occasion currents tending to keep open the mouths of estuaries, but it is nevertheless the prevailing tendency. The idea which sometimes appears in popular writings that embayments of the coast are eaten out by the ocean is a survival of the antiquated theory that the sculpture of the land is a result of "marine denudation." It is now understood that the diversities of land topography are wrought by stream erosion.

Plate XIV is copied from the work of the U. S. Lake Survey and represents about 20 miles of the east coast of Lake Michigan. It is evident from an inspection of the topography that the coast line was more sinuous when the waves first began to beat upon it at their present level. For example, the hill designated Sleeping Bear must have extended farther lakeward so as to constitute a cape. It has been so far eroded that the coast line now sweeps past it in a simple curve. Similarly, the Empire Bluffs have arisen from the excavation of a hill which once extended farther lakeward. And, in general, every cliff upon the coast marks the removal or partial removal of what was once a promontory. Between the Sleeping Bear and the Empire Bluffs there is evidence of the correlative result. The two lakelets delineated close to the shore are lagoons partitioned from the lake by bars joining the hills, and the smooth contour of the coast about the bay where Glen Arbor stands suggests that this, too, is a point of accumulation for shore drift and that a wave built terrace is forming. The more southerly lagoon and its bar are also pictured in plate VIII, which likewise illustrates the smooth sweeping curve of the shore.

IV.—STREAM WORK; THE DELTA.

The detritus brought to lakes by small streams is overwhelmed by shore drift and merges with it. The tribute of large streams, on the contrary, overwhelms the shore drift and accumulates in deltas. In the formation of a normal delta the stream is the active agent, the lake is the passive recipient, and waves play no essential part.

The process of delta formation depends almost wholly on the following law: *The capacity and competence of a stream for the transportation of detritus are increased and diminished by the increase and diminution of the velocity.* The capacity of a stream is measured by the total load of débris of a given fineness which it can carry. Its competence is measured by the maximum size of the particles it can move. A swift current is able to transport both more matter and coarser matter than a slow current. The competence depends on the velocity of the water at the bottom of the channel, for the largest particles the stream can move are merely rolled along the bottom. Finer particles are lifted from the bottom by threads of current tending more or less upward and before they sink again are carried forward by the general flow. Their suspension is initiated by the bottom current, but the length and speed of their excursion depend on the general velocity of the current. Capacity is therefore a function of the velocity of the more superficial threads of current as well as of those which follow the bottom.

Suppose that a river freighted with the waste of the land is newly made tributary to a lake. Its water flows to the shore, and shoots out thence over the relatively still lake water until its momentum has been communicated by friction to so large a body of water as to practically dissipate its velocity. From the shore outward the velocity at the bottom is the velocity of the lake water and not that of the river water, and is inconsiderable. The entire load consequently sinks to a final resting-place and becomes a deposit. The coarse particles go down in immediate contiguity to the shore. The finest are carried far out before they escape from the superficial stratum of river water.

The sinking of the coarse material at the shore has the effect of building out a platform at the level of the bottom of the river channel. Postulate the construction of this platform for some distance from the shore without any modification of the longitudinal profile of the river, the river surface descending to the shore and then becoming horizontal. Evidently, the horizontal portion has no energy of descent to

propel it, and yet is opposed by friction; its velocity is, therefore, retarded, its capacity and competence are consequently diminished, and it drops some of its load. The fall of detritus builds up the bottom at the point where it takes place, and causes a checking of the current immediately above (up stream). This in turn causes a deposit; and a reciprocation of retardation and deposition continues until the profile of the stream has acquired a continuous grade from its mouth at the extremity of the new platform backward to some steeper part of its channel—a continuous grade sufficient to give it a velocity adequate to its load. The postulate is, of course, ideal. The river does not in fact build a level bed and afterward change it to a slope, but carries forward the whole work at once, maintaining continuously an adjustment between its grade and its work. Moreover, since the deposition begins at some distance from the mouth, the lessening load does not require a uniform grade and does not produce it. The grade diminishes gradually lakeward to the foot of the deposit slope, so that the longitudinal profile is slightly concave upward. At the head of the deposit slope there is often an abrupt change of grade. At its foot, where the maximum deposit is made, there is an abrupt change of a double character; the incline of the river surface is exchanged for the horizontal plane of the lake surface; the incline of the river bottom is exchanged for the steeper incline of the delta front.

The river current is swifter in the middle than at the sides, and on a deposit slope, where velocity is nicely adjusted to load, the slight retardation at the sides leads to deposition of suspended matter. A bank is thus produced at either hand, so that the water flows down an elevated sluice of its own construction. The sides are built up *pari passu* with the bottom, but inasmuch as they can be increased only by overflow, they never quite reach the flood level of the water surface. A river thus contained, and a river channel thus constructed, constitute an unstable combination. So long as the bank approximates closely to the level of the surface at flood stage the current across the bank is slower than the current of the stream, and deposits silt instead of excavating. But whenever an accidental cause so far lowers the bank at some point that the current across it during flood is swifter than that of the main stream, there begins an erosion of the bank which increases rapidly as the volume of escaping water is augmented. A side channel is thus produced which eventually becomes deeper than the main or original channel and draws in the greater part or perhaps all of the water. The ability of the new channel to drain the old one depends on two things: first, the outer slope of the bank, from the circumstances of its construction, is steeper than the descent of the bottom of the channel; second, the first-made channel, although originally following the shortest route to the lake, has so far increased its length by the extension of its mouth that the water escaping over its bank may find a shorter

route. The river channel is thus shifted, and its mouth is transferred to a new point on the lake shore.

Repetition of this process transfers the work of alluvial deposition from place to place, and causes the river to build a sloping plain instead of a simple dike. The lower edge of the plain is everywhere equidistant from the head of the deposit slope, and has therefore the form of a circular arc. The inclination is in all directions the same, varying only with the diminishing grade of the deposit slope, and the form of the plain is thus approximately conic. It is, in fact, identical with the product of land-shaping known as the alluvial cone or alluvial fan. The symmetry of the ideal form is never attained in fact, because the process of shifting implies inequality of surface, but the approximation is close in all cases where the grade of the deposit slope is high, or where the area of the delta is large as compared with the size of the channel.

At the lake shore the manner of deposition is different. The heavier and coarser part of the river's detrital load, that which it pushes and rolls along the bottom instead of carrying by suspension, is emptied into the lake and slides down the face of the delta with no impulse but that given by its own weight. The slope of the delta face is the angle of repose of this coarse material, subject to such modification as may result from agitation by waves. The finer part of the detritus, that which is transported by suspension, is carried beyond the delta-face, and sinks more or less slowly to the bottom. Its distribution depends on its relative fineness, the extremely fine material being widely diffused, and the coarser falling near the foot of the delta face. The depth of the deposit formed from suspended material is greatest near the delta and diminishes gradually outward, so that the slope of the delta face merges by a curve with the slope of the bottom beyond.

As the delta is built lakeward, the steeply inclined layers of the delta face are superimposed over the more level strata of the lake bottom and in turn come to support the gently inclined layers of the delta plain, so that any vertical section of a normal delta exhibits at the top a zone of coarse material, bedded with a gentle lakeward inclination, then a zone of similar coarse material, the laminations of which incline at a high angle, and at bottom a zone of fine material, the laminations of which are gently inclined and unite by curves with those of the middle zone.

The characters of the fossil delta, or the delta as it exists after the desiccation of the lake concerned in its formation, are as follows: The upper surface is a terrace with the form of an alluvial fan. The lower slope or face is steep, ranging from 10° to 25°; it joins the upper slope by an angle and the plain below by a gentle curve. The line separating the upper surface from the outer slope or face is horizontal and, in common with all other horizontal contours of the structure, is approximately a circular arc. The upper or landward limit of the upper

BAR JOINING ISLAND TO MAINLAND, LAKE SUPERIOR, NEAR MARQUETTE.

[illegible] shifted, and [illegible] is transferred [illegible]

[illegible] process transfers the [illegible] of alluvial deposition [illegible] place, [illegible] instead [illegible] plain is everywhere eq[illegible] and has therefore the form of [illegible] the same, giving [illegible] the deposit [illegible], and the form of [illegible] fact, identical with [illegible] as the [illegible] cone or alluvial fan. [illegible] form is never attained in fact, because the [illegible] equality of [illegible] the approximation [illegible] the grade of the deposit slope is high or [illegible] is large as compared with the size of the [illegible]

[illegible] the manner of deposition is different. The heavier [illegible] the river's detrital load, that which it pushes and [illegible] bottom instead of carrying by suspension, [illegible] slides down the face of the delta with no impulse [illegible] given by its own weight. The slope of the delta face is the angle of repose of this coarse material, subject to such modification as may result from agitation by waves. The finer part of the detritus, [illegible] supported by suspension, is carried beyond the delta-face, and sinks more or less slowly to the bottom. Its distribution depends on [illegible] relative fineness, the extremely fine material being widely [illegible] the coarser falling near the foot of the delta face. The [illegible] of the deposit formed from suspended material is greatest near [illegible] and diminishes gradually outward, so that the slope of the delta face merges by a curve with the slope of the bottom beyond.

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BAR JOINING ISLAND TO MAINLAND. LAKE SUPERIOR, NEAR MARQUETTE.

surface is a line horizontally uneven, depending on the contours of the antecedent topography. The lower limit of the face is a verti-

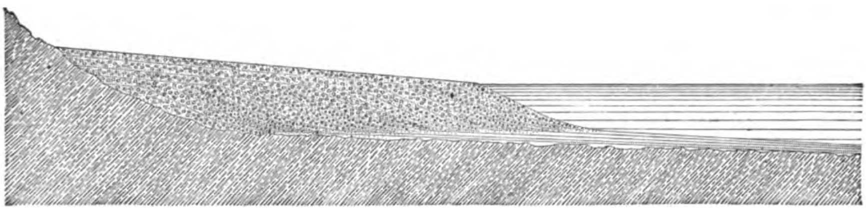


FIG. 4.—Ideal section of a Delta.

cally uneven line depending on the antecedent topography as modified by lake sediments. The material is detrital and well rounded; it exhibits well-marked lines of deposition, rarely taking the character of bedding. The structure as seen in section is tripartite. In the upper division the lines of deposition are parallel to the upper surface of the delta; in the middle division they are parallel to the steep outer face, and in the lower division they are gently inclined. The separation of the middle division from the lower is obscure. Its separation from the upper is definite and constitutes a horizontal plane. The fossil delta is invariably divided into two parts by a channel running from its apex to some part of its periphery and occupied by a stream, the agent of its construction becoming, under changed conditions of base level, the agent of demolition.

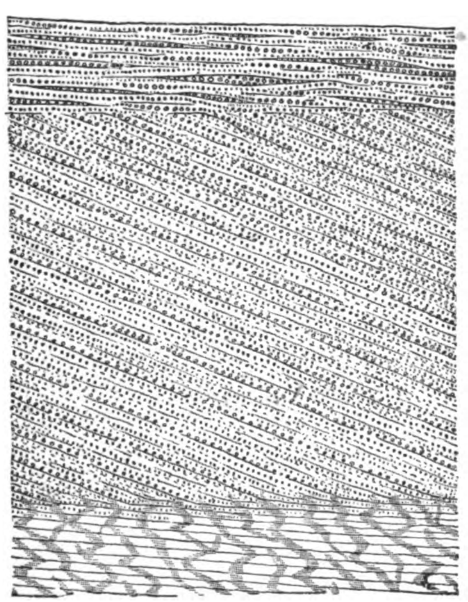


FIG. 5.—Vertical section in a Delta, showing the typical Succession of Strata.

The fan-like outline of the normal delta is modified wherever wave action has an importance comparable with that of stream action. Among the great variety of forms resulting from the combination of the two agencies there is one which repeats itself with sufficient frequency to deserve special mention. It occurs where the force of the waves is considerable and the amount of shore drift brought by them to the delta is inconsiderable. In such case the shore current from either direction is deflected by the mass of the delta, and wave action adjusts the contour of the delta to conformity with the deflected shore current. If the wave influences from opposite directions are equal, the delta takes the form of a symmetric triangle similar to that of the V-terrace.

Numerous illustrations are to be seen on the shores of Seneca Lake, where the conditions are peculiarly favorable. The lake is long and narrow, so that all the efficient wave action is associated with strong shore currents, and these alternate in direction. The rock of the sides is a soft shale, so easily triturated by the waves that the entire product of its erosion escapes with the undertow, and no shore drift remains. The sides are straight, and each tributary stream builds out a little promontory at its mouth to which the waves give form. Some of these triangular deltas embody perfectly the Greek letter, but they turn the apex toward the water instead of toward the land.

V.—ICE-WORK; THE SHORE WALL.

This feature does not belong to lakes in general, but is of local and exceptional occurrence. It was first explained by Dr. C. A. White.[11] The ice on the surface of a lake expands while forming so as to crowd its edge against the shore. A further lowering of temperature produces contraction, and this ordinarily results in the opening of vertical fissures. These admit the water from below, and by the freezing of that water are filled, so that when expansion follows a subsequent rise of temperature the ice cannot assume its original position. It consequently increases its total area and exerts a second thrust upon the shore. Where the shore is abrupt the ice itself yields, either by crushing at the margin or by the formation of anticlinals elsewhere; but if the shore is generally shelving, the margin of the ice is forced up the acclivity and carries with it any bowlders or other loose material about which it may have frozen. A second lowering of temperature does not withdraw the protruded ice margin but initiates other cracks and leads to a repetition of the shoreward thrust. The process is repeated from time to time during the winter, but ceases with the melting of the ice in the spring. The ice formed the ensuing winter extends only to the water margin, and by the winter's oscillations of temperature can be thrust landward only to a certain distance, determined by the size of the lake and the local climate. There is thus for each locality a definite limit, beyond which the projection of bowlders cannot be carried, so that all are deposited along a common line, where they constitute a ridge or wall. (See Fig. 7, Plate IV.)

The base of a shore wall stands somewhat above and beyond the ordinary margin of the water. It is parallel to the water margin, following its inflections. Its size is probably determined in fact by the supply of material, but there must also be a limit dependent on the strength of the ice formed in the given locality. Its material is usually coarse, containing bowlders such as the waves generated on the same lake would be unable to move. These may be either smooth or angular, heavy or light, the process of accumulation involving no discrimination.

Shore walls are not found on the margins of large lakes, for whatever record the ice of winter may make is obliterated by the storm waves of summer. Neither do they occur on the shores of very deep lakes, for such do not admit a heavy coating of ice; and for the same reason they are not found in warm climates. So far as the writer is aware they have never been found in the fossil condition, except that in a single instance a series of them serves to record very recent changes of level.

[11] Amer. Naturalist, v. 2, pp. 146–149.

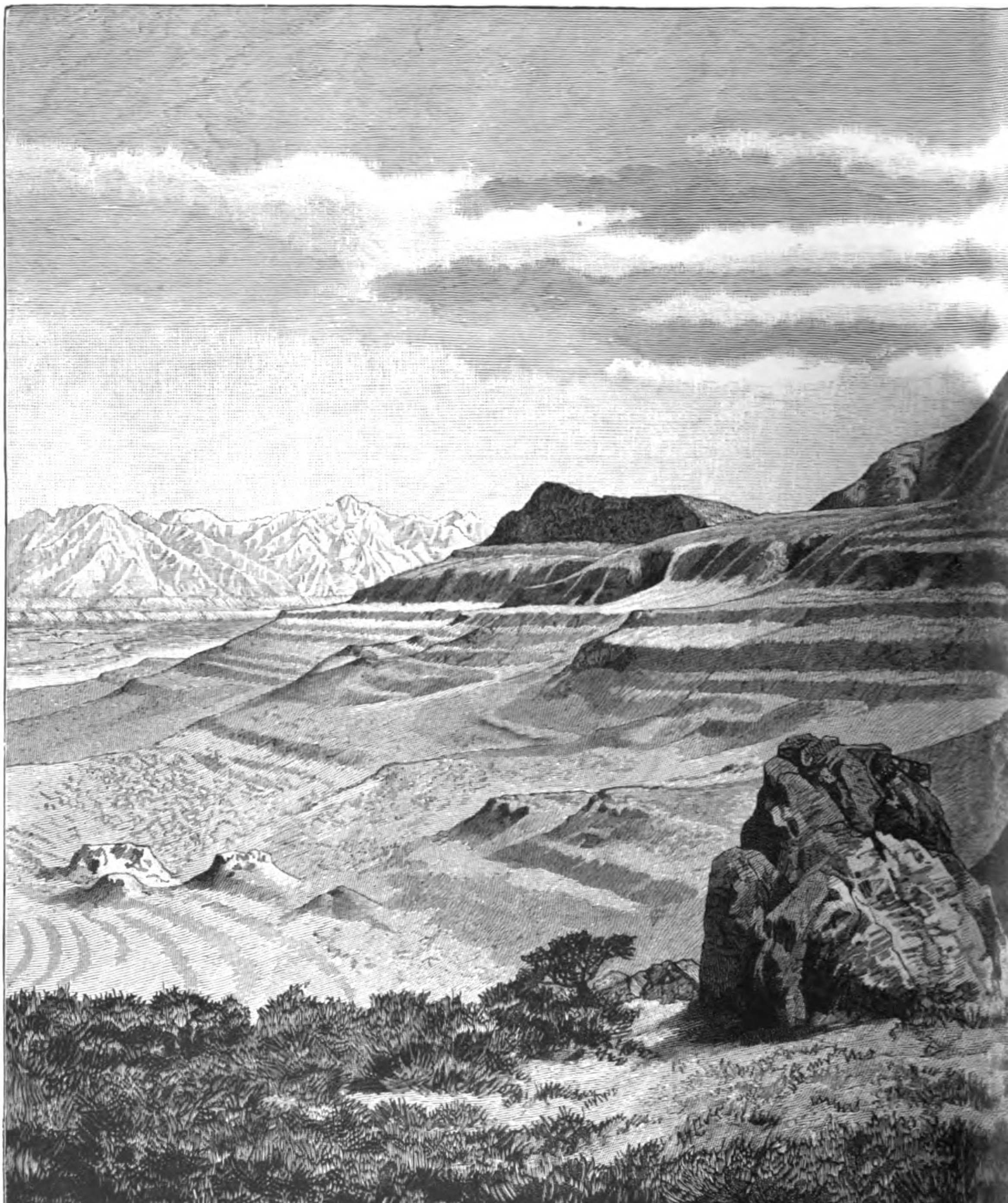
VI.—SUBMERGENCE AND EMERGENCE.

In the preceding discussion the general relation of the water surface to the land has been assumed to be constant. In point of fact it is subject to almost continuous change and its mutations modify the products of littoral shaping.

Lakes with outlet lower their water surfaces by corrading the channel of outflow. Lakes without outlet continually oscillate up and down with changes of climate; and finally, all large lakes, as well as the ocean, are affected by differential movements of the land. The series of displacements which in the geologic past has so many times revolutionized the distribution of land and water, has not ceased; and earth movements are so nearly universal at the present time that there are few coasts which betray no symptoms of recent elevation or subsidence. In this place it is unnecessary to consider whether the relation of water surface to land is affected by mutations of the one or of the other; and the terms emergence and submergence will be used with the understanding that they apply to changes in the relation without reference to causes of change.

The general effect of submergence or emergence is to change the horizon at which shore processes are carried on; and if a considerable change of level is affected abruptly the nature of the processes and the character of their products are not materially modified. The submerged shore line retains its configuration until it is gradually buried by sediments. An emerged shore line is subjected to slow destruction by atmospheric agencies. Only the delta is rapidly attacked, and that is merely divided into two parts by the stream which formed it. In the case of submergence the new shore constructed at a higher horizon is essentially similar to the one submerged. In the case of emergence the new shore constructed at a lower horizon rests upon the smooth contours wrought by lacustrine sedimentation, and, finding in the configuration little that is incongruous with its shore currents, carves few cliffs and builds few embankments. The barrier is usually one of its characteristic elements.

A slow and gradual submergence modifies the products of littoral action. The erosion of sea-cliffs is exceptionally rapid, because the gradually deepening water upon the wave-cut terraces relieves the waves from the task of carving the terraces and enables them to spend their full force against the cliffs. The cliffs are thus beaten back before the advancing tide and their precipitous character is maintained with constant change of position.



SEA-CLIFFS AND TERRACES CARVED BY THE WAVES OF LAKE B...

ONNEVILLE ON THE NORTH END OF OQUIRRH RANGE, UTAH.

A rhythm is introduced in the construction of embankments. For each level of the water surface there is a set of positions appropriate to the initiation of embankments, and with an advancing tide these positions are successively nearer and nearer the land; but with the gradual advance of water the position of embankments is not correspondingly shifted. The embankment constructed at a low stage controls the local direction of the shore current, even when its crest is somewhat submerged, and by this control it determines the shore drift to follow its original course. It is only when the submergence is sufficiently rapid to produce a considerable depth of water over the crest of the embankment that a new embankment is initiated behind it. The new embankment in turn controls the shore current, and by a repetition of the process a series of embankments is produced whose crests differ in height by considerable intervals.

A slow and gradual emergence causes the waves, in the *loci* of excavation, to expend their energies upon the terraces rather than the cliffs. No great cliffs are produced, but a wave-cut terrace is carried downward with the receding tide.

There is now no rhythm in the construction of embankments. At each successive lower level the shore drift takes a course a little farther lakeward, and is built into a lower embankment resting against the outer face of the one just formed. If, however, the emergence has been preceded by a submergence, so that a rhythmic system of embankments lies beneath the water, then, as each one is approached, it dominates the shore current and abruptly appropriates the shore drift.

The delta is very sensitive to emergence. As soon as the lake water falls from its edge, the formative stream, having now a lower point of discharge, ceases to throw down detritus and begins the corrasion of its channel. It ceases at the same time to shift its course over the surface of the original delta, but retains whatever position it happened to hold when the emergence was initiated. Coincidently it begins the construction of a new or secondary delta, the apex of which is at the outer margin of the original structure. With continued emergence a series of new deltas are initiated at points successively farther lakeward, and there is produced a continuous descending ridge divided by the channel of the stream.

So wide-spread are the evidences of recent emergence and submergence that normal shore features on a large scale are not easily selected for illustration. Few of the great slow-building deltas of the world assume the typical form; and submerged embankments are of such common occurrence beneath the waters of the Great Lakes that they have given rise to a widely prevalent theory that such structures are initiated beneath the water and either completed there or else gradually and tardily built to the surface.

VII.—THE DISCRIMINATION OF SHORE FEATURES.

A shore is the common margin of dry land and a body of water. The elements of its peculiar topography are little liable to confusion so long as they are actually associated with land on one side and water on the other; but after the water has been withdrawn by desiccation their recognition is less easy. They consist merely of certain cliffs, terraces, and ridges; and cliffs, terraces, and ridges abound in the topography of all land surfaces. In the following pages the topographic features characteristic of ancient shores will be compared and contrasted with other topographic elements likely to create confusion.

Such a discrimination as this has not before been attempted, although the principal distinctions upon which it is based have been the common property of geologists for many years. The contrast of stream terraces with shore terraces was clearly set forth by Dana in the American Journal of Science, in 1849, and has been restated by Geikie in his Text Book of Geology. It was less clearly enunciated by the elder Hitchcock in his Illustrations of Surface Geology.

CLIFFS

A cliff is a topographic facet in itself steep, and at the same time surrounded by facets of less inclination. The only variety belonging to the phenomena of shores is that to which the name "sea-cliff" has been applied. It will be compared with the cliff of differential degradation, the stream cliff, the coulée edge, the fault scarp, and the land-slip cliff.

THE CLIFF OF DIFFERENTIAL DEGRADATION.

It is a familiar fact that certain rocks, mainly soft, yield more rapidly to the agents of erosion than certain other rocks, mainly hard. It results from this, that in the progressive degradation of a country by subaerial erosion the minor reliefs are generally occupied by hard rocks while the minor depressions mark the positions of soft rocks. Where a hard rock overlies one much softer, the erosion of the latter proceeds so rapidly that the former is sapped, and being deprived of its support falls away in blocks, and is thus wrought at its margin into a cliff. In regions undergoing rapid degradation such cliffs are exceedingly abundant.

It is the invariable mark of a cliff of differential degradation that the rock of the lower part of its face is so constituted as to yield more rapidly to erosion than the rock of the upper part of its face. It is strictly

VIEW FROM THE EAST

RHYTHMIC SPITS OF LAKE BONNEVILLE AT WELLSVILLE, UTAH.

dependent on the constitution and structure of the terrane. It may have any form, but since the majority of rocks are stratified in broad, even sheets, and since the most abrupt alternations of texture occur in connection with such stratification, a majority of cliffs of differential degradation exhibit a certain uniformity and parallelism of parts. The crest of such a cliff is a line parallel to the base, and other associated cliffs run in lines approximately parallel. The most conspicuous of the cliffs of stratified rocks occur where the strata are approximately horizontal; and these more often than any others have been mistaken for sea-cliffs.

Plate XVIII gives a view of the upper portion of the south wall of the Grand Cañon of the Colorado, as seen from the foot of Toroweap Valley. The upper members of the rock series at that point are, first, a compact limestone, and second, a friable argillaceous sandstone. The latter by its rapid decay saps or undermines the former, causing it to fall away in large blocks and thus producing a vertical escarpment or cliff. Beneath the friable sandstone is a firmer sandrock constituting the floor of the terrace below the cliff, and this in turn rests on a series of massive limestones. Between the beds of limestone are softer layers, the presence of which is revealed in the profile by sloping benches interrupting the face of the lower cliff.

THE STREAM CLIFF.

The most powerful agent of land erosion is the running stream, and, in regions undergoing rapid degradation, corrasion by streams so far exceeds the general waste of the surface that their channels are cut down vertically, forming cliffs on either hand. These cliffs are afterward maintained by lateral corrasion, which opens out the valley of the stream after the establishment of a base level has checked the vertical corrasion. Such cliffs are in a measure independent of the nature of the rock, and are closely associated with the streams. They stand as a rule in pairs facing each other and separated only by the stream and its flood plain. The base of each is a line inclined in the direction of the stream channel and in the same degree. The crest is not parallel thereto, but is an uneven line conforming to no simple law.

THE COULÉE EDGE.

The viscosity of a lava stream is so great, and this viscosity is so augmented as its motion is checked by gradual cooling, that its margin after congelation is usually marked by a cliff of some height. The distinguishing characters of such a cliff are that the rock is volcanic, with the superficial features of a subaerial flow. It has probably never been mistaken for a sea cliff, and receives mention here only for the sake of giving generality to the classification of cliffs.

THE FAULT SCARP.

The faulting of rocks consists in the relative displacement of two masses separated by a fissure. The plane of the fissure is usually ap-

proximately vertical, and by virtue of the displacement one mass is made to project somewhat above the other. The portion of the fissure wall thus brought to view constitutes a variety of cliff or escarpment, and has been called a fault scarp. In the Great Basin such scarps are associated with a great number of mountain ranges, appearing generally at their bases, just where the solid rock of the mountain mass is adjoined by the detrital foot-slope. They occasionally encroach upon the latter, and it is in such case that they are most conspicuous as well as most likely to be mistaken for sea cliffs. Although in following the mountain bases they do not vary greatly in altitude, they yet never describe exact contours, but ascend and descend the slopes of the foot-hills. The crest of such a cliff is usually closely parallel to the base for long distances, but this parallelism is not absolute. The two lines gradually converge at either end of the displacement. In exceptional instances they converge rapidly, giving the cliff a somewhat

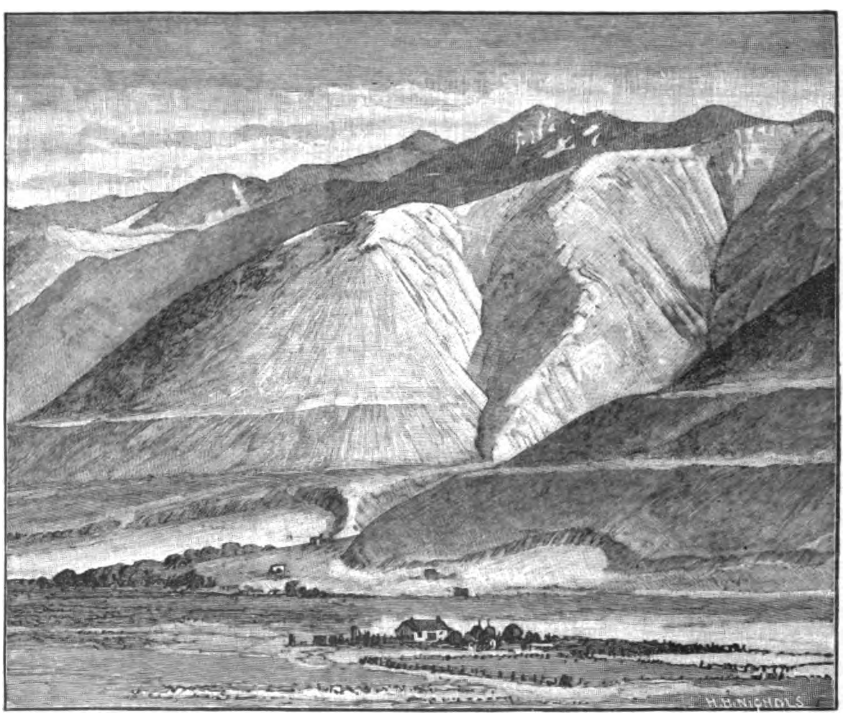


FIG. 6.—Fault Scarps and Shore Lines at the base of the Wasatch.

abrupt termination, and in such case a new cliff appears *en échelon*, continuing the displacement with a slight offset.

One of these fault-scarps with a course unusually curved is shown in figure 6, which is a view of the western face of the Wasatch Mountains near the town of Farmington, Utah. The same view exhibits higher

on the slope two wave-cut terraces belonging to the shores of Lake Bonneville at different epochs. The lake terraces are older than the fault scarp.

THE LAND-SLIP CLIFF.

The land slip differs from the fault chiefly in the fact that it is a purely superficial phenomenon, having its whole history upon a visible external slope. It occurs usually in unconsolidated material, masses of which break loose and move downward short distances. The cliffs produced by their separation from the general or parent mass, are never of great horizontal extent, and have no common element of form except that they are concave outward. They frequently occur in groups, and are apt to contain at their bases little basins due to the backward canting which forms part of the motion of the sliding mass.

COMPARISON.

The sea-cliff differs from all others, first, in that its base is horizontal, and, second, in that there is associated with it at one end or other a beach, a barrier, or an embankment. A third valuable diagnostic feature is its uniform association with the terrace at its base; but in this respect it is not unique, for the cliff of differential degradation often springs from a terrace. Often, too, the latter is nearly horizontal at base, and in such case the readiest comparative test is found in the fact that the sea-cliff is independent of the texture and structure of the rocks from which it is carved, while the other is closely dependent thereon.

The sea-cliff is distinguished from the stream-cliff by the fact that it faces an open valley broad enough and deep enough to permit the generation of efficient waves if occupied by a lake. It is distinguished from the coulée edge by its independence of rock structure and by its associated terrace. It differs from the fault scarp in all those peculiarities which result from the attitude of its antecedent; the water surface concerned in the formation of the sea-cliff is a horizontal plane; the fissure concerned in the formation of the fault scarp is a less regular, but essentially vertical plane. The former crosses the inequalities of the pre-existent topography as a contour, the latter as a traverse line.

The land-slip cliff is distinguished by the marked concavity of its face in horizontal contour. The sea-cliff is usually convex, or, if concave, its contours are long and sweeping. The former is distinguished also by its discontinuity.

TERRACES.

A terrace is a horizontal or nearly horizontal topographic facet interrupting a steeper slope. It is a limited plain, from one edge of which the ground rises more or less steeply, while from the opposite edge it descends more or less steeply. It is the "tread" of a topographic step.

Among the features peculiar to shores there are three terraces—the wave-cut, the wave-built, the delta. These will be compared with the terrace by differential degradation, the stream terrace, the fault terrace, and the land-slip terrace.

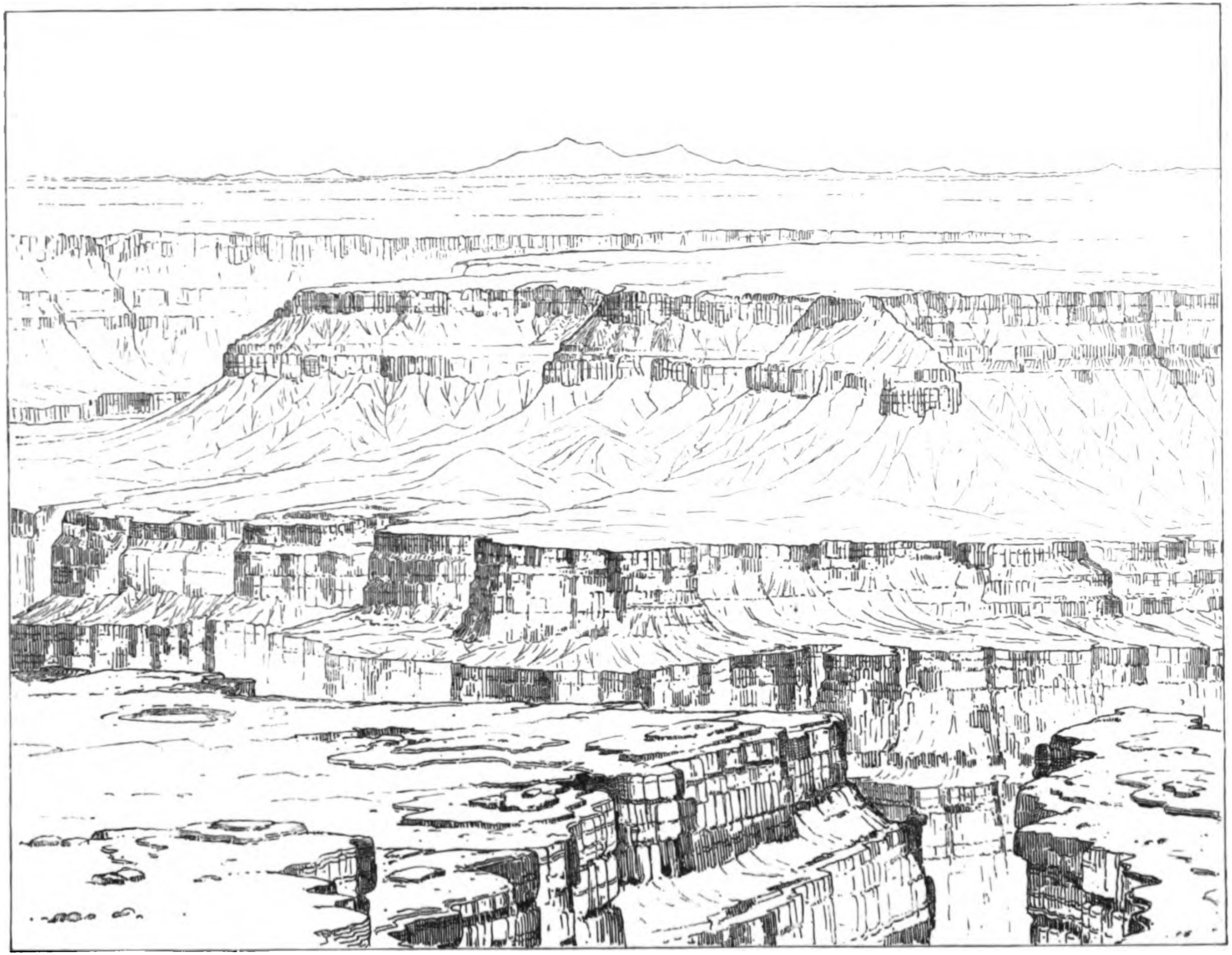
THE TERRACE BY DIFFERTIAL DEGRADATION.

The same general circumstances of rock texture which under erosion give rise to cliffs produce also terraces, but the terraces are of less frequent occurrence. The only case in which they are at all abundant, and the only case in which they need be discriminated from littoral terraces, is that in which a system of strata, heterogeneous in texture and lying nearly horizontal, is truncated, either by a fault or by some erosive action, and is afterwards subjected on the truncated section to slow atmospheric waste. The alternation of hard and soft strata gives rise under such circumstances to a series of alternating cliffs and terraces, the outcrop of each hard stratum appearing in a more or less vertical cliff, and the outcrop of each soft stratum being represented by a gently sloping terrace united to the cliff above by a curve, and, in typical examples, separated from the cliff below by an angle.

The length of such terraces in the direction of the strike is usually great as compared with their width from cliff to cliff. They are never level in cross profile, but (1) rise with gradually increasing slope from the crest of one cliff to the base of the next, or (2) descend from the crest of one cliff to a medial depression, and thence rise with gradually-increasing slope to the base of the next. The first case arises where the terrace is narrow or the dip of the strata is toward the lower cliff, the second case where the terrace is broad *and* the dip of the rocks is toward the upper cliff. In the first case the drainage is outward to the edge of the lower cliff; in the second it is toward the medial depression, whence it escapes by the narrow channels carved through the rock of the lower cliff. The first case is illustrated by the view in Plate XVIII.

THE STREAM TERRACE.

The condition of rapid erosion in any region is uplift. In a tract which has recently been elevated, the rate of degradation is unequal, the waste of the water channels being more rapid than that of the surface in general, so that they are deeply incised. Eventually, however, the corrasion of the water channels so reduces their declivities that the velocities of current suffice merely for the transportation outward of the detritus disengaged by the general waste of surface. In other words, a base level is reached. Then the process of lateral corrasion, always carried on to a certain extent, assumes prominence, and its results are rendered conspicuous. Each stream wears its banks, swinging from side to side in its valley, always cutting at one side and at the other building a shallow deposit of alluvium, which constitutes its



SOUTH WALL OF THE GRAND CAÑON OF THE COLORADO, SHOWING CLIFFS AND TERRACES OF DEGRADATION.

flood plain. The valley, having before consisted of the river channel margined on either side by a cliff, now consists of a plain bounded at the sides by cliffs and traversed by the river channel.

If now the corrasion of the stream bed is accelerated by a new uplift or other cause, a smaller valley is excavated within the first and at a lower level. So much of the original flood plain as remains constitutes a terrace flanking the sides of the new valley. Outwardly it is bounded by the base of the old line of cliffs, which may by decay have lost their vertical habit. Inwardly it is bounded by the crest of the new line of cliffs produced by lateral corrasion.

Acceleration of downward corrasion is brought about in many ways. As already mentioned, it may be produced by a new uplift, and this stimulus is perhaps the most potent of all. It is sometimes produced by the downthrow of the tract to which the streams discharge, or what is nearly the same thing, by the degradation of stream channels in that tract. It is also brought about within a certain range of conditions by increase of rainfall; and finally it always ensues sooner or later from the defect of transported material. The general waste of the originally uplifted tract undergoes, after a long period, a diminution in rapidity. The streams have therefore less detritus to transport. Their channels are less clogged, and they are enabled to lower them by corrasion. Perhaps it would be better to say that after the immediate consequences of uplift have so far passed away that an equilibrium of erosive action is established, the degradation of the entire tract proceeds at a slow continuous rate, the slight variations of which are in a sense accidental. Lateral corrasion under such circumstances coexists in all stream channels with downward corrasion, and is the more important process, but the horizon of its action is continuously lowered by the downward corrasion. The terraces which result represent only the stages of a continuous process.

In a great number of stream valleys, not one but many ancient flood plains find record in terraces, so that the stream terrace is a familiar topographic feature.

When a stream meandering in a flood plain encroaches on a wall of the valley and corrades laterally, it carries its work of excavation down to the level of the bottom of its channel; and afterward, when its course is shifted to some other part of the valley, it leaves a deposit of alluvium, the upper surface of which is barely submerged at the flood stage of the stream. The depth of alluvium on the flood plain is therefore measured by the extreme depth of the current at high water. It constitutes a practically even sheet, resting on the undisturbed terrane beneath. When the stream finally abandons it, and by carving a deeper channel, converts it into a terrace, the terrace is necessarily bipartite. Above, it consists of an even layer of alluvial material, fine at top and coarse at bottom; below, it consists of the pre-existent formation, whatever that may be. Where the lower portion is so constituted as to resist

[illegible] blanket, and then the [illegible] carried away by the [illegible] of the alluvium is the [illegible] scope of the second [illegible] [illegible]able.

[illegible] the opposite direction [illegible] aspect [illegible] terraces. Each of [illegible] It is [illegible] divided [illegible] another from the [illegible] and its [illegible] Usually the [illegible] brow of the [illegible] This [illegible] steep than [illegible] in the opposite [illegible] always coincides with the [illegible] terrace is [illegible] but undulates [illegible]

[illegible] TERRACE.

[illegible] to the fault terrace, but is less [illegible] of [illegible] extent. Its length is [illegible] when motion takes place [illegible] so that the sliding [illegible] its [illegible] surface, constituting the terrace, has a less in[illegible] Frequently this effect is carried [illegible] the terrace toward the cliff which overlooks it, [illegible] of the terrace is connected with the cliff in such [illegible]

[illegible] terrace of such origin is [illegible] observed. The surface is [illegible] as in the illustration, and where the slides occur in groups, as is their habit, the hillside is thrown into a billowy condition suggestive of the surface of a terminal moraine.

The landslip terrace bears so little resemblance to any shore terrace that its detailed description would seem out of place in this connection [illegible] fact that a false observation has actually [illegible] based

[illegible] bounded by faults has been called by the [illegible] [illegible] topography [illegible] on account of the [illegible] are [illegible] Science, are [illegible]

BIRD'S-EYE VIEW OF MADISON VALLEY, MONTANA, SHOWING STREAM TERRACES.

erosion, it loses after a long period its alluvial blanket, and then the terrace consists simply of the floor of hard rock as pared away by the meandering stream. The coarse basal portion of the alluvium is the last to disappear; and if it contains hard bowlders some of these will survive as long as the form of the terrace is recognizable.

THE FAULT TERRACE.

It sometimes occurs that two or more fault scarps with throw in the same direction, run parallel to each other on the same slope, thus dividing the surface into zones or tracts at various heights. Each of these tracts contained between two scarps is a terrace. It is a dissevered section of the once continuous general surface, divided by one fault from that which lies above on the slope and by another from that which lies below. It is the top of a diastrophic block,[12] and its inclination depends upon the attitude of that block. Usually the block is tilted in a direction opposite at once to that of the throw of the limiting faults and to that of the general slope of the country. This has the effect of giving to the terrace an inclination less steep than that of neighboring plains, or (exceptionally) of inclining it in the opposite direction.

In the direction of its length, which always coincides with the strike of the faults, the terrace is not horizontal, but undulates in sympathy with the general surface from which it has been cut.

THE LAND-SLIP TERRACE.

This is closely related in cross-profile to the fault terrace, but is less regular and is of less longitudinal extent. Its length is frequently no greater than its width. The surface on which motion takes place has a cross-section outwardly concave, so that the sliding mass moves on an arc, and its upper surface, constituting the terrace, has a less inclination than in its original position. Frequently this effect is carried so far as to incline the terrace toward the cliff which overlooks it, and occasionally the edge of the terrace is connected with the cliff in such way as to form a small lake basin.

An even terrace of such origin is rarely observed. The surface is usually hummocky, as in the illustration, and where the slides occur in groups, as is their habit, the hillside is thrown into a billowy condition suggestive of the surface of a terminal moraine.

The land-slip terrace bears so little resemblance to any shore terrace that its detailed description would seem out of place in this connection, were it not for the fact that a false observation has actually been based upon it.

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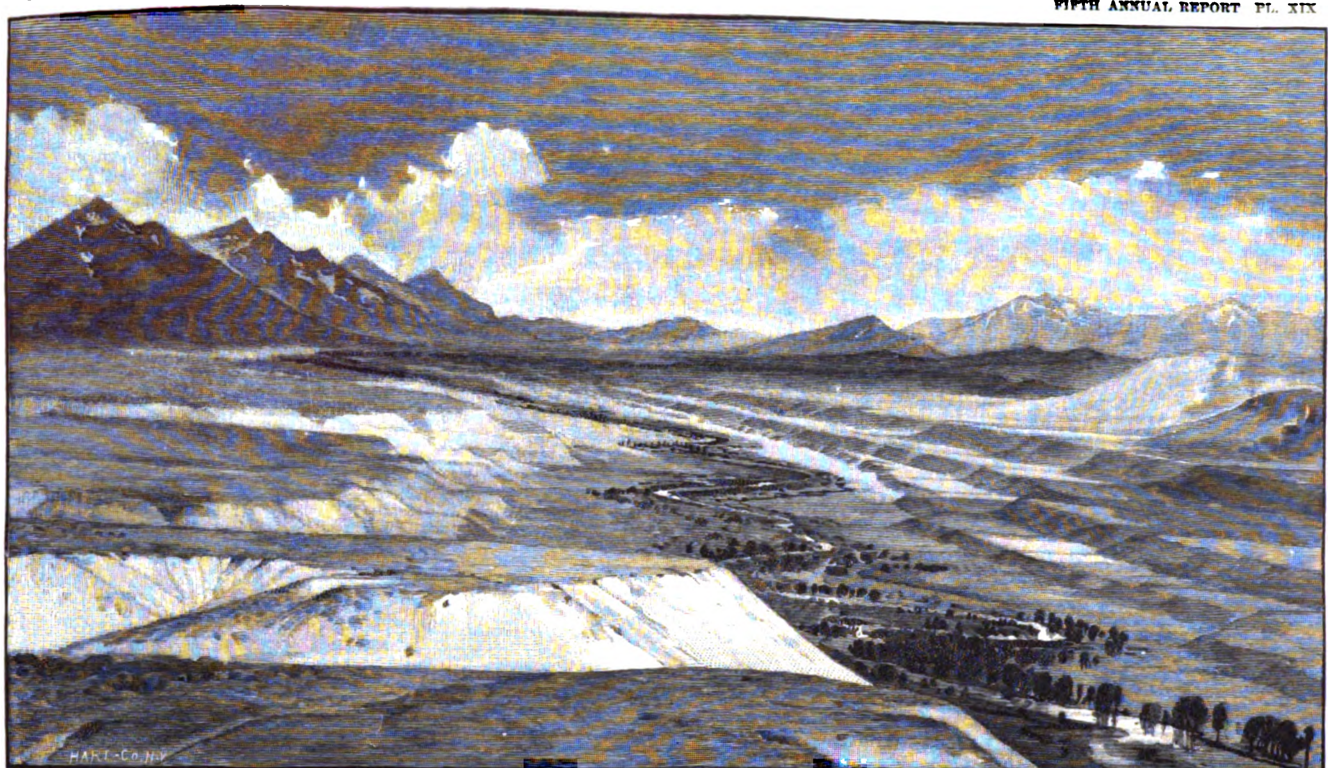
[12] A prism of the earth's crust bounded by faults has been called by the writer and others an "orographic block," but the adjective "orographic" has been felt, by the writer at least, to be highly objectionable on account of the implication of its etymology. The word "diastrophic" and the corresponding noun "diastrophism," suggested by Major J. W. Powell and first employed in a letter to Science, are free from this objection and commend themselves to students of displacement.



BIRD'S-EYE VIEW OF MADISON VALLEY, MONTANA, SHOWING STREAM TERRACES.

COMPARISON.

The only feature by which shore terraces are distinguished from all terraces of other origin, is the element of horizontality. The wave-cut terrace is bounded by a horizontal line at its upper edge; the delta is bounded by a horizontal line about its lower edge; and the wave-built terrace is a horizontal plain. But the application of this criterion is rendered difficult by the fact that the terrace of differential degradation is not infrequently margined by horizontal lines; while the inclination of the base of the stream terrace, though a universal and essential character, is often so small in amount as to be difficult of recognition. The fault terrace and land-slip terrace are normally so uneven that this character sufficiently contrasts them with all shore features.

The wave-cut terrace agrees with all the non-shore terraces in that it is overlooked by a cliff rising from its upper margin, and differs from them in that it merges at one end or both with a beach, barrier, or embankment. It is further distinguished from the terrace of differential degradation by the fact that its configuration is independent of the structure of the rocks from which it is carved, while the latter is closely dependent thereon. In freshly formed examples, a further distinction may be recognized in the mode of junction of terrace and cliff. As viewed in profile, the wave-cut terrace joins the associated sea-cliff by an angle, while in the profile wrought by differential degradation, the terrace curves upward to meet the overlooking cliff.

The wave-cut terrace is distinguished from the stream terrace by the fact that it appears only on the margin of an open basin broad enough for the propagation of efficient waves, whereas the latter usually margins a narrow or restricted basin. In the case of broad terraces a further distinction is found in the fact that the shore terrace descends gently from its cliff to its outer margin, whereas the stream terrace is normally level in cross-section. In fresh examples the alluvial capping of the stream terrace affords additional means of discrimination.

There are certain cases in which the wave-formed and stream terraces merge with each other and are difficult of separation. These occur in the estuaries of ancient lakes, where the terraces referable to wave-action are confluent with those produced contemporaneously by the lateral corrasion of streams. The stream being then tributary to the lake, could not carry its erosion to a lower level, and its zone of lateral corrasion was at its mouth continuous with the zone of wave erosion in the lake.

The wave-built terrace may be distinguished from all others by the character of its surface, which is corrugated with parallel, curved ribs. It differs from all except the stream terrace in its material, which is wave-rolled and wave-sorted. It differs from the stream terrace in that it stands on a slope facing an open basin suitable for the generation of waves.

The delta differs from all except the stream terrace in its material and in its constant relation to a water-way. Its material is that known

[illegible] is always [illegible] [illegible] normal stream terrace [illegible] to the lakeward [illegible] the normal stream terrace [illegible] [illegible] age of [illegible] [illegible] stream terraces [illegible] its horizontal [illegible] [illegible] test on the [illegible]

[illegible] flood plain is independent of [illegible] [illegible] altered [illegible] and [illegible] basins. [illegible] of the stream may be completely filled [illegible] its upper [illegible]; and [illegible] there is nothing in the superficial [illegible] from the normal flood plain.

[illegible] of [illegible] terrestrial degradation is further [illegible] terraces by the fact [illegible] of [illegible] [illegible] [illegible] salients. Where the shore [illegible] is an irregular [illegible] appear only at the salients, and in the reentrants [illegible] [illegible] and deltas.

RIDGES.

[illegible] The [illegible] [illegible] [illegible] [illegible] [illegible] matter. In the first [illegible] the ridge is continuous with that of the [illegible] in the second it is not; and the [illegible] [illegible] ridges which fall within the second class, are [illegible] [illegible] confused with ridges of the first class. They will [illegible] be compared in this place only with other [illegible] posed [illegible] [illegible] barrier, the embankment, and the shore wall are [illegible] will be contrasted with the moraine and the osar.

THE MORAINE.

[illegible] consist [illegible] by glaciers at their lateral [illegible] [illegible] The material of these [illegible] [illegible] are consolidated. It includes large blocks, [illegible] [illegible] and these are [illegible] [illegible] are striated. The [illegible]

LAND SLIPS IN MARSH VALLEY, IDAHO.

as stream drift. Its mass is always divided by a stream channel so as to lie partly on each bank; its terminal contour is a circular arc centering on some point of the channel; and it is usually confluent in the ascending direction with the normal stream terrace. Indeed, when considered with reference to the dividing channel, it is a stream terrace; and it is only with reference to the lakeward margin that it is a shore terrace. It is distinguished from the normal stream terrace by its internal structure. The high inclination of the lamination of its middle member—formed by the discharge of coarse detritus into standing water—is not shared by the stream terrace, while its horizontal alluvium does not, as in the case of the stream terrace, rest on the pre-existent terrane.

Since the formation of the delta is independent of wave-action, it may and does take place in sheltered estuaries and in small basins. A small lake interrupting the course of the stream may be completely filled by the extension of the delta built at its upper extremity; and when this has occurred there is nothing in the superficial phenomena to distinguish the formation from the normal flood plain.

The terrace of differential degradation is further distinguished from all shore terraces by the fact that, without great variations in width, it follows the turnings of the associated cliff, conforming to it in all its salients and re-entrants. Where the shore follows an irregular contour, wave-cut terraces appear only on the salients, and in the re-entrants only wave-built terraces and deltas.

RIDGES.

Ridges are linear topographic reliefs. They may be broadly classed into those produced by the erosion or dislocation of the earth's surface and those built upon it by superficial transfer of matter. In the first class, the substance of the ridge is continuous with that of the adjacent plain or valley; in the second, it is not; and this difference is so obvious that shore ridges, which fall within the second class, are not in the least liable to be confused with ridges of the first class. They will therefore be compared in this place only with other imposed ridges. Of shore phenomena, the barrier, the embankment, and the shore wall are ridges. They will be contrasted with the moraine and the osar.

THE MORAINE.

The detritus deposited by glaciers at their lateral and terminal margins is usually built into ridges. The material of these is fragmental, heterogeneous, and unconsolidated. It includes large blocks, often many tons in weight, and these are angular or subangular in form. Sometimes their surfaces are striated. The crest of the moraine is not

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horizontal, but descends with the general descent of the land on which it rests.

Moraines are found associated with mountain valleys, and also upon open plains. In the first case their crests are narrow, and their contours are in general regular. The lateral moraines follow the sides of the valleys, often standing at a considerable height above their bottoms, and are united by the terminals, which cross from side to side with curved courses whose convexities are directed down-stream. The moraines of plains have broad, billowy crests abounding in conical hills and in small basins.

THE OSAR OR KAME.

These names are applied to an indirect product of glacial action. It is multifarious in form, being sometimes a hill, sometimes a ridge, and often of more complicated form. It doubtless embraces types that need to be separated; but it is here sufficient to consider only the linear form. As a ridge its trend is usually in the direction of glacial motion. Its material is water-worn gravel, sand, and silt, with occasional bowlders. Its contours are characteristically, but not uniformly, irregular. Its crest is usually, but not uniformly, uneven. When even, it is parallel to the base or to that upon which the base rests; or, in other words, the ridge tends to equality of height rather than to horizontality.

COMPARISON.

The shore ridges are primarily distinguished from the glacial ridges by the element of horizontality. The barrier and the embankment are level-topped, while the shore wall has a level base and is so low that the inequality of its crest is inconsiderable. It is only in exceptional cases and for short distances that moraines and osars exhibit horizontality. Shore-ridges are further distinguished by their regularity. Barriers and embankments are especially characterized by their smoothness, while smooth osars are rare, and the only moraine with even contours is the lateral moraine associated with a narrow valley.

Other means of discrimination are afforded by the component materials, and the moraine is thus clearly differentiated. The barrier and the embankment consist usually of sand or fine gravel, from which both clay and larger bowlders have been eliminated. Except in immediate proximity to the sea cliff whose erosion affords the detritus, the pebbles and bowlders are well rounded. The material of the shore wall has no special qualities, but is of local derivation, the ridge being formed simply by the scraping together of superficial débris. The moraine contains heterogeneous material ranging from fine clay to very large, angular blocks. The materials of the osar are normally less rounded than those of normal shore ridges.

Certain osars of great length, even figure, and uniform height are distinguished from barriers by the greater declivity of their flanks, and by the fact that they do not describe contours on the margins of basins.

VIII.—THE RECOGNITION OF ANCIENT SHORES.

The facility and certainty with which the vestiges of ancient water margins are recognized and traced depend on local conditions. The small waves engendered in ponds and in sheltered estuaries are far less efficient in the carving of cliffs and the construction of embankments than are the great waves of larger water bodies; and the faint outlines they produce are afterward more difficult to trace than those strongly drawn.

The element of time, too, is an important factor, and this in a double sense. A water surface long maintained scores its shore mark more deeply than one of brief duration, and its history is by so much the more easily read. On the other hand a system of shore topography, from which the parent lake has receded, is immediately exposed to the obliterating influence of land erosion and gradually, though very slowly, loses its character and definition. The strength of the record is directly proportioned to the duration of the lake and inversely to its antiquity.

It will be recalled that in the preceding description the character of horizontality has been ascribed to every shore feature. The base of the sea-cliff and the coincident margin of the wave-cut terrace are horizontal; and so is the crest of each beach, barrier, embankment, and wave-built terrace, and they not merely agree in the fact of horizontality, but fall essentially into a common plane—a plane intimately related to the horizon of the maximum force of breakers during storms. The outer margin of the delta is likewise horizontal, but at a slightly lower level—the level of the lake surface in repose. This difference is so small that for the purpose of identification it does not affect the practical coincidence of all the horizontal lines of the shore in a single contour. In a region where forests afford no obstruction, the observer has merely to bring his eye into the plane once occupied by the water surface, and all the horizontal elements of shore topography are projected in a single line. This line is exhibited to him not merely by the distinctions of light and shade, but by distinctions of color due to the fact that the changes of inclination and of soil at the line influence the distribution of many kinds of vegetation. In this manner it is often possible to obtain from the general view evidence of the existence of a faint shore tracing, which could be satisfactorily determined in no other way. The ensemble of a faintly scored shore mark is usually easier to recognize than any of its details.

It is proper to add that this consistent horizontality, which appeals so forcibly and effectually to the eye, cannot usually be verified by instru-

mental test. The surface of the "solid earth" is in a state of change, whereby the vertical relations of all its parts are continually modified. Wherever the surveyor's level has been applied to a fossil shore, it has been found that the "horizon" of the latter departs notably from horizontality, being warped in company with the general surface on which it rests. The level, therefore, is of little service in the tracing of ancient water margins, while the water margins afford, through the aid of the level, delicate measures of differential diastrophic movements. It might appear that the value of horizontality as an aid to the recognition of shores is consequently vitiated, but such is not the case. It is, indeed, true that the accumulated warping and faulting of a long period of time will so incline and disjoint a system of shore features that they can no longer be traced; but it is also true that the processes of land erosion will in the same time obliterate the shore features themselves. The minute elements of orographic displacement are often paroxysmal, but so far as observation informs us, the general progress of such changes is slow and gradual, so that, during the period for which shore tracings can withstand atmospheric and pluvial waste, their deformation is not sufficient to interfere materially with their recognition.

THE REQUISITE AND QUALIFYING CONDITIONS

OF

ARTESIAN WELLS.

BY

THOMAS C. CHAMBERLIN.

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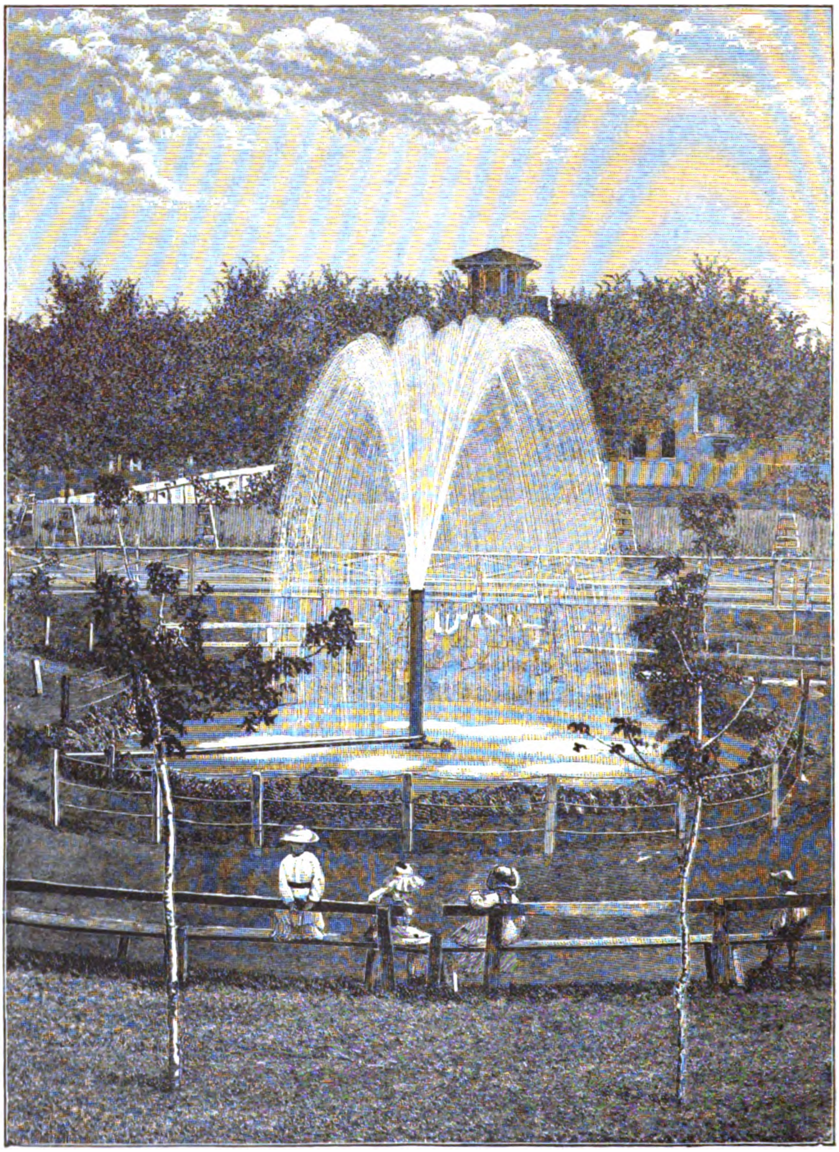

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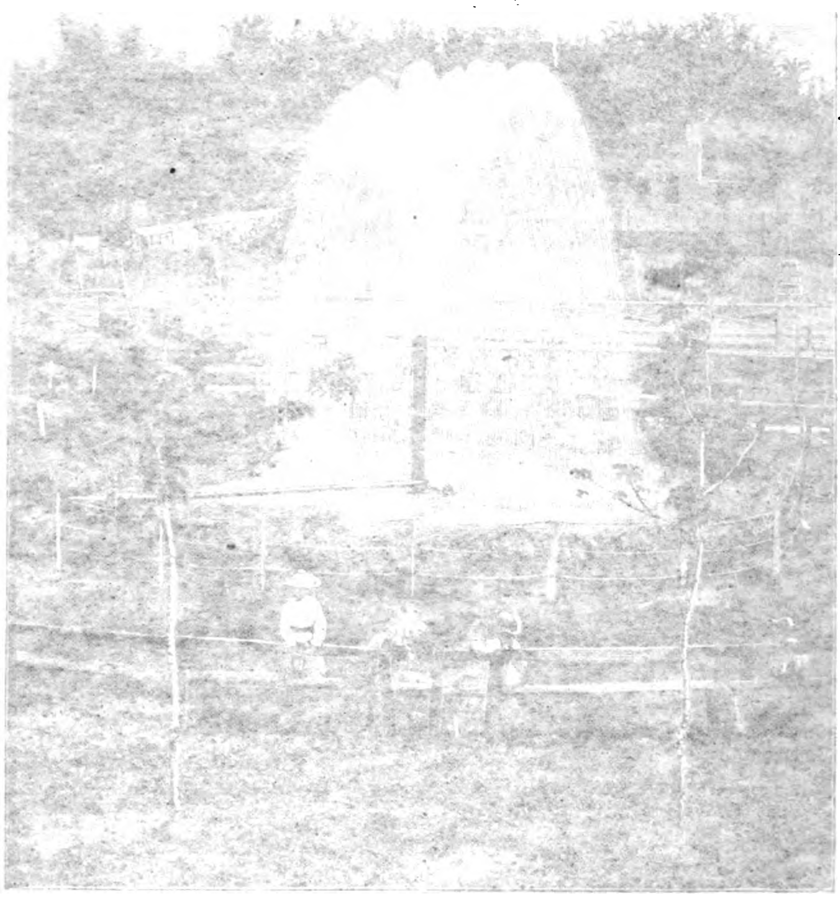

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REQUISITE AND QUALIFYING CONDITIONS OF ARTESIAN WELLS.[1]

By T. C. Chamberlin.

INTRODUCTION.

The basal principles of artesian wells are simple. The school-boy reckons himself their master. But the real problems they present are complex. It is a combination of varying conditions, rather than the application of simple principles, that determines success or failure. A clear statement of these conditions is as rare as a simple, but incomplete, exposition is familiar. This is perhaps not so much due to any special intricacy of the problem, or to any grave obstacle to a clear statement, as to the simple fact that it has been neglected.

It has not been the leading subject of any profession. Few drillers make the causes and conditions of artesian flow a special study, or find it within their province to master the geological elements of the question. Few geologists, among the multitude of more obtrusive resources pressed upon their attention, find themselves able to pursue the subject into its practical details. Few citizens have occasion more than once or twice in their lives to give the matter special consideration. This, however, is growing steadily less and less true. Drillers are developing the sinking of artesian wells into a specialty, and, through the aid of geological reports, are mastering the stratigraphical elements of the problem in their several regions. Geologists are solicited with increased frequency for advice and prognostic opinions. Citizens are becoming more widely interested in both the practical and the theoretical aspects of the subject.

Its importance does not need argument, though it may need emphasis. The problem of a pure and adequate water supply is among the gravest questions that now lay under tribute the thoughts of sanitarians. Artesian wells form one, but only one, source of such a supply; sometimes as

[1] The term artesian wells in this discussion is applied only to those that flow at the surface. Unfortunately the term is frequently used to denote deep wells that do not flow, a use that is to be condemned.

inadequate or impracticable as, at others, generous and beneficent. Were they an unfailing source, a universal possibility, so great a resource would command its own full measure of attention. Were they always inadequate, or unsatisfactory, they might be easily dismissed. This inconstant feature is an element that makes need for a discriminative discussion of the conditions that determine success or failure, since they are a valuable resource in certain regions and under certain limitations, while, in other regions and beyond assignable limits, they are only a lure to useless expenditure. On the one hand, large sums are needlessly spent in endeavors to obtain these fountains, where the essential conditions are altogether wanting, and, on the other, large possibilities of good have lain neglected, to the great sanitary and industrial loss of citizens.

It is the aim of this article to gather into a simple and convenient form such information relative to the necessary and qualifying conditions of artesian wells as may be capable of brief, general statement, and may seem to be serviceable alike to citizen, driller, and geologist. There will be no attempt, however, to make it an exhaustive exposition of the subject from the individual stand-point of either. The citizen will desire specific information concerning cost, quality of water, etc., that cannot be answered in a general discussion. The driller will desire constructive details and local particulars relating to the succession of beds, the texture and structure of the rock, etc., that only exhaustive geological descriptions, specially interpreted for his purpose, can supply. The geologist will desire a fuller discussion of the elements that enter into the formation of a professional opinion. It is obvious that, so far as these are dependent on local and varying conditions, satisfactory general answers are impracticable, and, in so far as they are specifically technical, they are here inappropriate. It is the ground of common interest, lying in the conditions of success, that I aim to cover. In addition to all that can be said here, special problems will need special study.

If there lingers in the mind any sense of marvel at the flow of artesian wells, it is best to cast it away at the outset. Artesian flow is but an expression of the common law of flowage, made a little unusual, it is true, by its special conditions. Any seeming strangeness springs from our partial observation. We see but a part of the stream. The rest lies hidden in the earth's depths, a realm which the imagination is prone to people with mysteries. Moreover, the part we do most see is a *rising* stream, that comes gushing up in the face of the dogma that water "never runs up hill." But water flowing up hill is one of the commonest facts of nature, an every day, an everywhere occurrence, illustrated in every brook, rill, and river, not to say spring. Stir up a little trash in the bottom of any deep pool in a brook, and see how readily it is borne up the slope of the pool-bed, and out over the shallows below. Disturb

the bottom mud above a dam, and watch it ascend the steep slope, and pass over the weir.

Certain portions of the water of every stream are always "running up hill," though its average mass is moving down.

FIG. 7.—Longitudinal section of a stream, illustrating, in part, its upward currents, subordinate to the general downward flowage.

The bottom layer flows up and down according to the inequalities of the bed, while the top layer declines more uniformly with the surface slope.[2] In proportion as the stream is rapid and crooked, these layers exchange places, and there is a tortuous upward and downward flow, in addition to that directly enforced by the bottom inequalities, though all are largely due to these. The flowing up is merely a way of flowing down, *i. e.*, the rising of a part permits the descent of a greater portion, or the greater descent of an equal or less part. No portion would rise, if it were not forced up by a superior portion pressing down. In the artesian stream, we only see the rising column issuing from the earth,

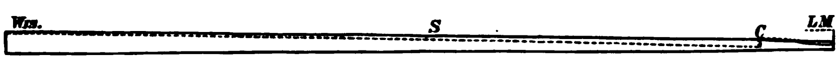

FIG. 8.—Section of the Chicago artesian stream, drawn to a nearly true scale. The dotted line represents the course of flow, exhibiting the long declining stream from the fountain-head in south-central Wisconsin, the short and *relatively* trivial rise in the wells at Chicago (C of the diagram), and the surface flow from these. The full line, G, representing the surface, shows the general decline of the stream. For the purpose of giving clear and striking illustrations, most diagrams of artesian wells are given enormously exaggerated vertical scales, and most of those of this paper are quite disproportionate in that respect, though the exaggeration has been greatly reduced. This diagram is introduced at the outset to forestall the erroneous impressions conveyed by such illustrations.

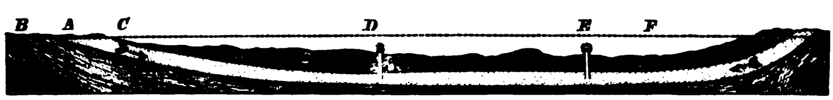

FIG. 9.—Ideal section illustrating the chief requisite conditions of artesian wells. A, a porous stratum; B and C, impervious beds below and above A, acting as confining strata; F, the height of the water-level in the porous bed A, or, in other words, the height of the reservoir or fountain-head; D and E flowing wells springing from the porous water-filled bed A.

and the brooklet that flows away. The more potent descending volume that forces the flow is concealed. This it is the mind's task to picture clearly.

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[2] It is not a little surprising to note how frequently this simple fact, common to all streams, is neglected in the study of glacial flows. The traces of extinct glacial currents are those formed by the bottom of the stream, whose ascending and descending courses are no stranger than those of the brook. We study one from the top and neglect the bottom, the other from the bottom and forget the top.

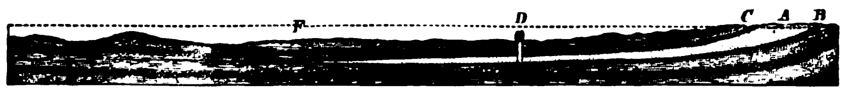

FIG. 10.—Section illustrating the thinning out of a porous water-bearing bed, A, inclosed between impervious beds, B and C, thus furnishing the necessary conditions for an artesian fountain, D.

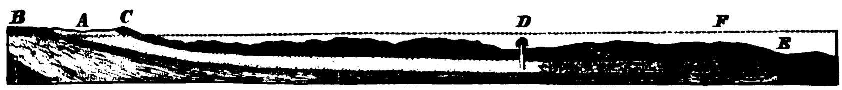

FIG. 11.—Section illustrating the transition of a porous water-bearing bed, A, into a close-textured impervious one. Being inclosed between the impervious beds B and C, it furnishes the conditions for an artesian fountain, D.

ESSENTIAL FEATURES OF ARTESIAN WELLS.

The artesian stream has its source, its underground water-way, its ascent through the well, and its final descent in the rill that runs away. It is peculiar mainly in its underground conditions. Upon these, chiefly, the ascending flow depends.

Typical examples.—To fashion a simple idea of the common class of flowing wells, picture to the mind a pervious stratum through which water can readily pass. Below this let there be a water-tight bed, and let a similar one lie upon it, so that it is securely embraced between impervious layers. Suppose the edges of these layers to come to the surface in some elevated region (save that they may be covered with soil and loose surface material), while in the opposite direction they pitch down to considerable depths, and either come up again to the surface at some distance, thus forming a basin (Fig. 9), or else terminate in such a way (Fig. 10) or take on such a nature (Fig. 11) that water cannot escape in that direction. Now, let rain-fall and surface-waters penetrate the elevated edge of the porous bed, and fill it to the brim. That such beds are so filled is shown by ordinary wells, which commonly find a constant supply in them at no great depth. Now it is manifest that if such a water-fat bed be tapped by a boring at some point lower than its outcrop, the water will rise and flow at the surface because of the higher head in the upper edge of the bed. If the surface-water continually supplies the upper edge as fast as the water is drawn off below, the flow will be constant.

Prerequisites.—The leading conditions upon which artesian flows depend are involved in this simple conception. Drawn out they are as follows:

I. A pervious stratum to permit the entrance and the passage of the water.

II. A water-tight bed below to prevent the escape of the water downward.

III. A like impervious bed above to prevent escape upward, for the water, being under pressure from the fountain-head, would otherwise find relief in that direction.

IV. An inclination of these beds, so that the edge at which the waters enter will be higher than the surface at the well.

V. A suitable exposure of the edge of the porous stratum, so that it may take in a sufficient supply of water.

VI. An adequate rain-fall to furnish this supply.

VII. An absence of any escape for the water at a lower level than the surface at the well.

These may be considered in detail, and then attention directed to some special practical questions.

THE WATER-BEARING BEDS.

There are two general methods by which water finds its way through the strata; in the one—the rock being close-textured—the water passes through fissures formed by fracture, or tubular channels formed by solution; in the other—the rock being open-textured—the water seeps through the pores, permeating the whole bed.[3]

1. *Fissured and channeled beds.*—Beds that offer only crevices and channels as water-ways are a very uncertain source of fountains, for open, continuous avenues of this class do not seem to be abundant in strata deeply buried, and the position of such as exist cannot be determined beforehand, so that there is no certainty of striking them.

The close-textured rocks that fall under attention here are chiefly the crystalline class (the granites, greenstones, etc.) and the limestones. The clay rocks (shales, etc.) are too compact to be in any available degree water-bearing; indeed, they form the chief confining strata.

The crystalline rocks are much fissured at the surface, and shrinkage has opened gaping crevices in them; but these avenues largely close up and disappear at moderate depths, and there are no sufficient grounds for supposing that they often afford facilities for a continuous, generous flow, where they have always lain under the protecting mantle of impervious strata, and have suffered the pressure of their weight. Experience confirms this. None of the igneous or metamorphic rocks are to be accounted available water-bearing strata unless some known local condition gives them exceptional possibilities.

The limestones are likewise much traversed by crevices near the surface, and are, besides, subject to the solvent action of the waters passing through them. These often form extensive underground channels, mammoth examples of which are found in the great elongated caves of

[3] Of course we are here considering only such generous supplies as are available for artesian purposes, not that slower penetration of rocks by water that is almost or quite universal.

Indiana and Kentucky. But, like the above, these prevail mainly in the superficial portion of the beds, and are chiefly confined to regions where the limestone stratum is not overlain by other rocks, and hence not available as a source of fountains. The reason of this is manifest, when it is considered that the solvent action is mainly accomplished by surface waters. These exhaust their solvent power before penetrating far. When the limestone is overlain by impervious beds, these surface waters are cut off, and hence solvent action is limited to such waters as entered at the distant outcropping edge. The cracks and cavities of deep seated limestones are often found to be healed up with calcite, an index that the waters there are depositing, rather than solvent.

The grounds, therefore, for anticipating success in penetrating limestone for fountains, are not very flattering, though less adverse than in the crystalline rocks. However, limestones that have once been exposed to surface action, and thereby fissured and channeled, and subsequently buried beneath a thick mantle of drift clay, are not altogether unpromising. Not a few important flowing wells have been derived from them. But when the beds have always lain deeply buried beneath impervious strata, they have rarely been found productive, so far as my knowledge extends.

A little computation will show that even if such compact rocks were notably fissured and channeled, they would be a very questionable resource in deep, expensive wells. Suppose that vertical fissures or tubular channels traversed a given stratum at intervals of only 10 feet. It would be possible to sink twenty average bores between each two of them. If the fissures averaged as much as 6 inches, the chances of success would be about one in twenty, or only 5 per cent. of the whole, or, with a similar system of cross fissures, 10 per cent. If the case were really of this sort, however, connection with the channels might be made by firing torpedoes within the bore. But in fact deeply-buried limestones are to be esteemed a very uncertain dependence, while metamorphic and igneous rocks had better not be reckoned a dependence at all. Limestones that have been once at the surface, but afterward buried, may be locally serviceable.

2. *Porous beds.*—Quite in contrast with the close-textured beds, that are water-carriers only by virtue of fissures and channels, are the open-textured strata that constitute continuous water-filled sheets underspreading wide areas, and which can therefore almost certainly be tapped at the proper depth. Speaking in general terms, these are the only reliable sources of artesian wells.

To this class belong beds of sand, gravel, sandstone, conglomerate, and other less common rocks of loose granular texture. Some of the more porous chalks and granular limestones may be classed here. The common feature of the class lies in the construction of the rock from separate particles, loosely put together, leaving small open spaces between them. The porosity is of an interstitial, not vesicular, kind. A

bed of sand is a typical illustration, and it will not be wide of the truth to speak of the whole class as sandstones. All sandstones, however, are not sufficiently porous to furnish a ready passage for water. In some the interspaces are filled with clayey or other impervious matter, that insinuated itself among the particles as they were being deposited originally; in others the pores were subsequently choked by deposits from solution and by compacting under pressure.

The degree of porosity is a very important consideration, when the volume of the flow is to be considered. If the entire rock is made up of sand-like particles the larger these are, in general, the greater the water-conveying capacity. Some sandstones are so fine-grained as to be almost impervious. The water merely oozes through them, and they are quite incapable of furnishing a generous flow. Others are so open-spaced that floods flow freely through them. In nature there is every gradation, from open gravels to close sandstones.

Besides, there is almost every possible intermixture of coarse and fine material. The constituents were not perfectly assorted. Fine sand and silt are interspersed among coarser grains, pebbles, and bowlders. This may reach almost any degree of influence upon the water-carrying capacity of the rock from a slight reduction to its almost complete extinction.

There is also a very wide range in the degree of consolidation after deposition. There are drift sands and gravels that are entirely loose and uncompacted, while, at the other extreme, are perfectly consolidated quartzites and analogous rocks. It is a general but quite unreliable rule that consolidation varies with the age of the formation, the Quaternary sands being looser than the Tertiary, the Tertiary looser than the Secondary, and so on. The rule is founded on reason; but there are many notable exceptions, as the Potsdam sandstone of the Upper Mississippi Valley, among the most ancient of the old life series, and yet among the most loose-textured, as well as the most generous of water-bearers. It is manifest, therefore, that we cannot rest with simple rules or general descriptions. The capabilities of each formation must be ascertained by direct observation of its constitution. This indicates one of the good offices subserved by critical descriptions of the texture of rocks, even of those which are coarsest and whose origin is most obvious. It is a suggestion that examinations be made more critical.

THE CONFINING BEDS.

No stratum is entirely impervious. It is scarcely too strong to assert that no rock is absolutely impenetrable to water. Minute pores are well nigh all pervading. To these are added microscopic seams, and to these again larger cracks and crevices. Consolidated strata are almost universally fissured. Even clay beds are not entirely free from partings.

But in the study of artesian wells we are not dealing with absolutes but with availables. A stratum that successfully restrains the most of the water, and thus aids in yielding a flow, is serviceably impervious. It may be penetrated by considerable quantities of water, so that the leakage is quite appreciable and yet be an available confining stratum. The nearest approach to an entirely impervious bed is furnished by a thick layer of fine, unhardened clay. In this case solidifying permits the formation of fissures and the clay rocks are less impervious than the original clay beds. The clayey shales rank next as confining strata, after which follow in uncertain order shaly limestones, shaly sandstones, the various crystalline rocks, and even compact sandstones. Paradoxical as it may seem water itself may form a confining agent. I shall presently attempt to show that it is even an agency of considerable importance. In a different and more forced sense an illustration may be found in the pool of the brook before cited. The water flows from the bottom of the pool up the slope and out, because it is pressed by the water behind and *confined* by that above. Each upper layer is a confining stratum to each lower one. This, however, is not the sense in which it is a recognizable agency in artesian flows.

1. *The confining stratum below.*—It is our habit to be less solicitous about the tightness of the cover of a water-bearing vessel than of its bottom. The reverse is the case in artesian wells. The confining stratum

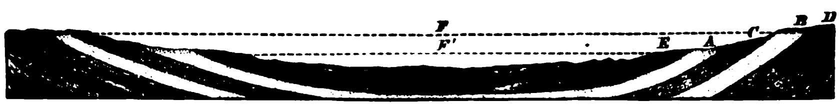

FIG. 12.—Section illustrating the usual order in which the strata of a basin come to the surface. A and B, porous beds; D and E, impervious beds; C, a half-impervious bed; F' and F the water levels of A and B, respectively.

beneath the porous bed demands less critical attention than that above, for if the layer next beneath the water-bed is defectively impervious, some lower layer will stop the water. It is only when the lower layers are so situated that they can carry the water out again to the surface, at a lower level than the water-bearing bed above, that they can discharge it, however leaky. This is not usually the case. As a rule, when beds are bent into a basin, or are inclined, the lower layers outcrop at

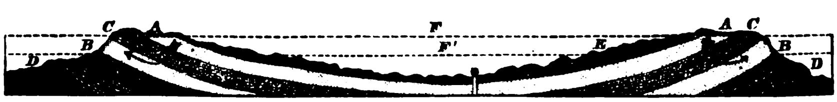

FIG. 13.—Section illustrating the possible effect of erosion upon strata originally like those in Fig. 6. A and B, porous beds; D and E, impervious beds; C, a half pervious bed: F and F' the water levels of A and B, respectively. If the stratum C is not practically a confining layer, the water from A will pass through it and escape at the edge of B, so that a flow cannot be obtained at a higher level than it, but may be had below the line F'.

higher elevations than those overlying them, as illustrated in Fig. 12. But this is not always so, and, even when so at first, unequal erosion

of the surface may reverse the order of height of outcrop, as illustrated in Fig. 13. The consequence of a possible defect in the layers underlying a water-bed are illustrated in Figs. 13 and 14, and the descriptions appended to them. The confining strata below cannot, therefore, be

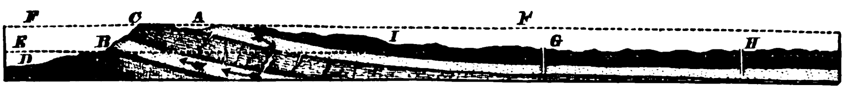

FIG. 14.—Section illustrating the failure of an artesian well, because of defects in a confining bed below. A and B, porous beds; D and I, impervious beds; C, a defective confining bed; E, the water level of the stratum B; G and H, wells that do not flow. The bed A might give a flow at G and H but for the defect in C, which permits the water to descend into B and escape through its outcrop, which lies below the surface of G and H.

neglected, though usually less imperative of critical attention than those above.

2. *The confining stratum above.*—The character of the strata that overlie the water-bearing bed is critically important, for the water, being under pressure, tends to rise through them, and, if they are in any degree penetrable, it will, to that extent, escape, and relieve the pressure, and thus reduce or prevent the flow. When the capacity of the water-bearing bed is great, and the fountain-head high, moderate defects in the cover-bed merely cause a reduction in the volume and height of flow; but when the conditions are closely balanced, either because of low head, feeble supply, or obstructed passage, he who assumes to foretell results has need to make careful estimate of the amount of leakage through the covering strata.

a. It may be noted that the leakage will be reduced in proportion as the pressure is lessened, so that, in nearly-balanced cases, the loss is less—other things being equal—than in cases of high head and free passage, *but it is more critical in determining success or failure.*

b. The most essential consideration, the nature of the rock, has already been discussed. In a more summary and general way it may be here restated that the effective imperviousness is somewhat nearly measured by the total amount of clayey constituents. But this is rather a convenient generalization than a safe rule.

c. Efficiency increases with thickness. If the cover-beds are of the highest impervious character, there is little need that they should be very thick, unless the fountain-head is so high that increased weight is needed to counterbalance the hydrostatic pressure—an improbable case. But when the degree of imperviousness is inferior, the element of thickness is not without consequence, in itself, and, taken in connection with the following point, may be decisive.

d. The element to be recognized here is, I believe, essentially new to discussions of the subject,[4] viz, the height of the surface of the common ground-water in the region between the proposed well and the

[4] I discussed this subject extemporaneously before the Wisconsin Academy of Science in December, 1880, but did not write it out for publication. The point is treated in Vol I, Geol. of Wis., p. 692.

fountain-head. It is a familiar fact that the common underground water stands at varying heights. Our common wells testify to this. The subterranean water-surface is almost invariably higher than the adjacent streams, and slowly works its way into them by springs, seeps, and invisible percolation. Speaking generally, the underground water-surface rises and falls with the rise and fall of the land-surface, only less in amount. Now, if the subterranean water in the region between the proposed well and its source—which we may call the cover-area—stands as high as the fountain-head (except at the well, where, of course, it must be lower), *there will be no leakage*, not even if the strata be somewhat permeable, for the water in the confining beds presses down as much as the fountain-head causes that of the porous bed to press up, since both have the same height. Capillarity does not disturb the truth of this. Under these conditions a flow may sometimes be secured when it would be impossible if the intervening water-surface were lower.

If the water between the well and fountain head is actually higher than the latter, it will tend to penetrate the water bearing stratum, so far as the overlying beds permit, and will, to that extent, increase the supply of water, seeking passage through the porous bed, and will, by reaction, tend to elevate the fountain-head, if the situation permit.

FIG. 15.—Section intended to illustrate the aid afforded by a high water-surface between the fountain-head and the well. A, a porous bed; B, a confining bed below; and C, a confining bed above. The dark line immediately below the surface represents the underground water-surface. Its pressure downward is represented by the arrow *m*. The pressure upward due to the elevation of the fountain-head is represented by the arrow *n*. The line F represents the level of the fountain-head. There can be no leakage upward through the bed C except near the well D. There may be some penetration from the bed C into A, which would aid the flow.

I conceive that one of the most favorable conditions for securing a fountain is found when thick semi-porous beds, constantly saturated with water to a greater height than the fountain-head, lie upon the porous stratum, and occupy the whole country between the well and its source, as illustrated by Figure 15. This is not only a good, but an advantageous, substitute for a strictly impervious confining bed. Under these hydrostatic conditions, limestone strata reposing on sandstone furnish an excellent combination.

If on the other hand the underground water-surface between the proposed well and the source of supply is much lower than the fountain-head there will be considerable leakage, unless the confining beds are very close-textured and free from fissures. For example, if it be 100 feet lower there will be a theoretical pressure of nearly three atmospheres, or about 45 pounds to the square inch upward, greater than that of the underground water downward, disregarding the influence of capillarity, and this will be competent to cause more or less

penetration of the water upward through the pores and crevices of the rocks, and consequent loss of head and forcing power.

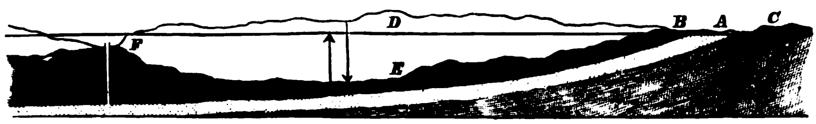

FIG. 16.—Double section illustrating the effects of high and low water-surface in the cover-area. (For explanation see text.)

Both of the above points may be illustrated by the accompanying double profile, in which A represents a porous stratum inclosed between the impervious beds B and C. The source of water-supply is at A, and the proposed well at F. Let E be supposed to represent the surface of the ground (and, for convenience, also, the surface of the common ground-water) in one of the two supposed cases, and D the surface in the other. The arrow springing from the surface E represents the upward tendency of the water in the porous bed, owing to pressure from the fountain-head, while the arrow depending from the line D represents the downward pressure of the ground-water whose surface is represented by D, and is, it will be observed, more than equivalent to the upward tendency due to pressure from the fountain-head. A flow at F could very safely be predicted if the surface were as represented by D, while it might be doubtful whether one could be secured if the surface were as represented by E.

My attention was first directed to this consideration by observing that where the intermediate country was elevated and had a high water-level, wells flowed at heights surprisingly near theoretical estimates, almost no deduction for obstruction and leakage being necessary, whereas in those cases where the opposite was true there was a very considerable falling short of theoretical estimates.

THE INCLINATION OF THE BEDS.

The water-bearing bed and the confining strata that embrace it must be inclined so that the edge which comes to the surface shall be higher than the surface at the proposed well, else there can be no elevated source of supply for the flow. The ideal conditions are furnished when the strata sag in the center, while the edges are upturned so as to form a basin. The water then enters the rim of the porous stratum and fills it up to the level of surface drainage. If, now, this saturated stratum be tapped somewhere toward the center of the basin, at a point lower than the water-level in the rim, a stream will be forced to the surface. But it is not really necessary that the beds form a basin. If they are inclined so as to expose their edges on one side, and if by any means

the porous bed is choked up in the other direction, so that the water cannot escape, a flow may be obtained without regard to what may be the position of the opposite edge. It is highly probable that our sandstone beds as they pass off from the old shore belt, along which they were formed, into what was then the deeper part of the ocean, gradually change from coarse, open sandstone to fine-grained rock, and so cease to be readily permeable to water. Along the South Atlantic border, for instance, there are sandstone beds that pitch down beneath the sea. But we have no need to search the coast of North Africa for the opposite edge, for there is no reason to doubt that the sandstones soon thin out under the ocean, and are replaced by a close-textured, deep-sea sediment. A similar fact is true of large basins generally. It is not necessary to consider the great interior basin defective because of the depressed lips through which the Mississippi and Mackenzie Rivers flow out of it. Experience teaches that we may safely neglect the opposite side of the basin in such cases and consider the problems presented as if the porous beds became impermeable somewhere in their downward extension.

But even if the sandstone formation is continuous and crops out at a lower point than the well, it is not necessarily impossible to secure a flow, though cases of this sort must be considered with much circumspection in attempts to prejudge success or failure. Another principle enters here and demands consideration. Let us recall the fact that sandstone strata are chiefly the product of wave action along shore belts and off-shore shallows. It stands to reason and observation that they are thickest and coarsest along the shore edge and thinner and finer in the off-shore portion. When these beds are afterwards lifted

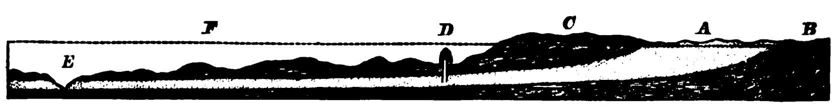

FIG. 17.—Section illustrating the possibility of a flow from a bed even when exposed at a lower level A, a sandstone bed, thick and coarse at the right, its shore edge, and thinner and finer at the left. B and C, confining impervious beds. F, the water level in A. D, a well which may flow notwithstanding the lower exposure at E.

and become part of the continent, the former shore border is almost universally most elevated, and becomes the entrance edge for subterranean waters. (See Figures 12 and 17.)

Now, this edge has a greater water-conveying capacity than the off-shore portion, both because it is thicker and because it is coarser and more open. If, therefore, the surface supply is generous and the outcrop in the opposite direction is distant, even though it is lower, it may be an inadequate means of discharge, because of the great resistance encountered by the water in threading its way so long a distance through the minute pores of the close rock. Under these conditions a well-bore near the fountain-head (as at D, in Figure 17) may offer to the water a route of less resistance. The greater ascent through the well

may be counterbalanced by the greater resistance of the long underground passage.

The element of resistance makes itself manifest even in cases where there is no reason to suspect a change either of thickness or of texture of rock. Several important wells at Oshkosh, Fond du Lac, Watertown, and Palmyra, Wis., flow from formations that outcrop, within 50 miles, at notably lower levels. These outcrops, however, are not in the line of slope from fountain-head to well, but more nearly along the line of strike at right angles to it. All these wells probably owe their success to the high subterranean water-level between the wells and their sources, as above explained, but resistance to flow through the water-bearing bed seems also to serve an important function, else the entire head would be relieved through the low outcrops.

It is, of course, to be borne in mind that resistance from friction is only developed when motion begins, and motion begins only when the water escapes, so that loss must always be reckoned when frictional resistance is assumed. The function of this resistance is only to render available a portion of the aqueous flow at a height greater than the lowest but inadequate outlet. The same principle is involved when several wells at different heights draw upon the same stratum.

Height of outcropping beds.—The relative height of the outcropping edge of the water-bearing stratum is a consideration of the first importance. It is obvious that this edge must be elevated, so that the water within it will stand high enough above the site of the proposed well to force an efficient flow after deduction is made for leakage and the obstruction encountered in the passage. How much higher than the well it must be is a complicated, practical problem, in which large deductions from theoretical estimates must often be made. It depends upon (1) the distance of the well from the source of supply; (2) the capabilities of the porous bed; (3) the character of the confining strata, and (4) the topography of the intervening land and the ground-water surface, as previously explained. These elements are so varying in their combination that it is impracticable to give any definite general rules applicable to wide areas. The best guide will be found in studying the results of experience in regions presenting conditions, as nearly as possible, similar to those of the proposed well. A study of the local and special conditions of any proposed well is essential to a trustworthy prophecy of results.

THE RESERVOIR OR FOUNTAIN HEAD.

It is often convenient to speak of the source of supply as the reservoir. Erroneous impressions, however, are likely to arise from the use of the term. Two such are quite current, and need to be dismissed. The one is the assumption that the reservoir is a surface lake, the other that it is an underground pool, occupying a cavernous cistern, as it were. A surface lake is an extremely improbable source of an artesian flow. It has already been indicated that the water must have a *ready*

entrance and flow through the porous stratum to give an efficient fountain. But most lakes owe their existence to the fact that they have impervious bottoms, otherwise the water would pass into the earth beneath. This fact stands in the way of their serving as sources of artesian wells. Far from being looked upon as special fountain-heads, lakes are to be regarded in precisely the opposite sense. They show that the rain-fall, instead of going into the strata to feed the fountain, is held at the surface and exposed to loss from evaporation and overflow.

The rain-fall of a region is discharged in three ways; (1) evaporation, (2) surface drainage, (3) underground percolation. Artesian wells can avail themselves only of the last. Whatever increases the first two decreases the last. In so far, therefore, as impervious surface basins aid evaporation and surface discharge they detract from the copiousness of the underground supply.

It is a compensating fact, however, that surface drainage is usually imperfect in lake regions, as the existence of the lakes themselves testifies. Possibly all, or more than the loss from evaporation, may be gained by this reduced surface flow. This, however, does not destroy the force of the general observation, that a lake is not to be regarded as the special reservoir of an artesian fountain.

The notion of a subterranean pool has little more to support it. Tubular channels and cavernous spaces undoubtedly exist, and are occasional sources of flow, or means of passage, and so are, in a sense, reservoirs, but not in the import of the term as used in connection with artificial fountains, *i. e.*, in the sense of a fountain-head.

The reservoir or fountain-head of most artesian wells is simply the water contained in the water-bearing stratum above the level of the point of flow, or, in other words, the water in the elevated margin of the water-filled stratum. To fashion a simple illustration, conceive a piece of lead tube to be inclined and filled with sand, the lower end being closed; let water be poured in until the sand is completely saturated. Now a miniature flowing well may be formed by drilling a small hole near the lower end. The water in the sand will run out, and, if renewed at the upper end, the flow will be continuous. This would be analogous to an artesian well, save that here there is a cylinder of water-filled sand, instead of a sheet. Now the reservoir in this case is the *water in the sand* in the upper part of the tube. In like manner, in artesian wells, the reservoir, so called, or the fountain-head, is the water contained in the elevated edge of the porous stratum.

This is supplied by the rain-fall, and we are thus led on, naturally, toward that ultimate source, but, on the way we will consider the means of gathering and delivering it to the water-carrying stratum.

THE COLLECTING AREA.

The outcropping edge of the porous stratum is practically the gathering area. Its extent depends not only upon the thickness of the bed, but

on the angle at which it comes to the surface and the effect of erosion upon it. If the porous bed is thin, and outcrops at a high angle, its edge will not occupy much space at the surface, and will consequently be incapable of gathering in a large supply from rain-fall. On the other hand, if the thickness is great, and if the stratum comes to the surface at a low angle, so that its beveled edge is wide, it will have considerable extension at the surface, and be competent to receive and transmit a large supply of water.

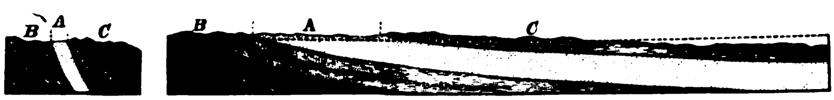

FIG. 18—Section showing the dependence of the collecting area on the thickness and slope of the porous beds. In the left-hand figure the porous bed A is thin, and, coming to the surface at a high angle, gives but a small section. In the right-hand figure the bed A is thick, and, coming to the surface at a low angle, its beveled edge is broad.

Effect of erosion and surface configuration.—Porous beds are usually more easily eroded than impervious ones, though this is by no means a universal rule. Soft clayey shale may be more erodable than even friable sandstone. The effect of greater erosion is usually a reduction of the surface area of the stratum, as illustrated in the accompanying figure.

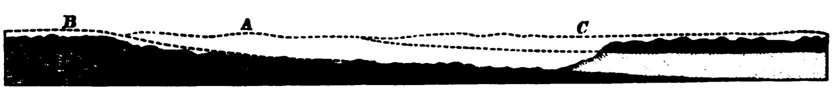

FIG. 19.—Illustrating a common effect of erosion upon the surface area of the porous stratum, and the contour of the resulting basin. The dotted lines show the original contours.

The adverse influence of this reduction is, in part, offset by the favorable contour of the depression so produced. A not uncommon form is a gently sloping plain, covered with a sandy absorbent soil, the natural result of the disintegration of the porous stratum, and these may render a nearly complete compensation.

The erosion of strata of unequal resistance usually results in very ragged, dissected edges. This may much increase the area tributary to the absorbent stratum, and be another source of compensation.

If the region of outcrop is much elevated, and the surface slopes are rapid, the rain-fall runs quickly away, and a less proportion of it is absorbed. In flatter regions, the surface discharge is less rapid and gives greater opportunities for subterranean percolation.

In considering questions relating to small wells, from which only a moderate discharge is demanded, it is sufficient to know, by the aid of ordinary wells sunk on the outcropping edge, what is the height of water and generosity of supply in the porous stratum; for, in regions of ordinary rain-fall, a very small surface will gather a sufficient amount. Even if the outcrop is very unfavorable, failure will not be likely to result from inadequacy of surface supply. But when very large delivery

is demanded, these considerations are not to be entirely neglected. Without doubt, inadequate delivery at the well is more often due to other causes; but a superabundant volume of water, pressing for entrance and passage through the porous bed, is a condition much to be desired when important and expensive enterprises are to be undertaken.

ADVANTAGES OF LOW INCLINATION OF THE STRATA.

In addition to presenting a larger collecting surface, there are two other advantages usually afforded by a low inclination of the strata:

1. If the productive bed dips but slightly, it lies within available reach beneath a larger area. If it dips rapidly, it soon attains a great depth, unless the surface slopes with corresponding rapidity.

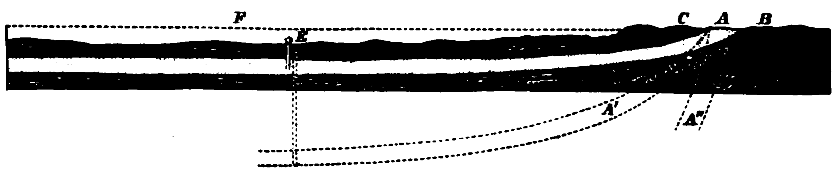

FIG. 20.—Section illustrating the advantages of low inclination. A, a porous bed; B and C, impervious beds. A' and A'' indicate porous beds of higher dip.

2. Another advantage is usually found in texture. The original position of sandstones and similar beds is essentially horizontal. If they are tilted, it is only because force has been brought to bear upon them. Some degree of compression and consolidation is the natural result of this action, increasing with its intensity. The porosity of highly disturbed beds is, therefore, liable to be inferior to that of those less disturbed, other things being equal.

So, also, the deeper the beds are buried the greater the weight of superincumbent strata, and the greater the tendency, probably, to the filling of the pores by depositions from infiltrating solutions.

The ideal stratigraphical conditions are found, therefore, when the beds have been gently lifted into an inclined position by a general crust movement, leaving them as little curved and depressed as is consistent with securing the proper head. A high and efficient flow depends more upon favorable conditions of underground passage than upon a high-rimmed, deeply depressed basin. This is not altogether the popular impression, fostered by the unnecessarily distorted figures of current treatises.

SURFACE CONDITION OF THE POROUS BED.

The facility with which water enters the porous stratum may be affected by the superficial mantle of soil and other unconsolidated material that conceals it. In those regions that are not overspread with Quaternary deposits of distant origin, the soil is mainly derived from the decomposition of the immediately underlying rock. In other words, the exposed margin of the bed has simply been disintegrated.

A porous rock usually gives origin to a still more absorbent soil, so that its decayed edge drinks in all the more readily the waters precipitated upon it. In the drift-bearing regions, the disintegrated surface was more or less rubbed away by glacial action, and then overspread by a sheet of mixed soil and rock-rubbish of the most varying character, sometimes absorbent, sometimes impervious, often presenting in its own alternating layers all the conditions (and sometimes the most fruitful ones) of artesian fountains. There is a certain disposition of the drift to partake of the nature of the stratum beneath, but this has important limitations. On the whole, the drift tends toward imperviousness, and has the effect of retaining the waters at the surface. Its superficial contour is usually irregular, having been formed under the compulsion of glacial action, and not in conformity to drainage demands, so that the water is discharged from the surface less promptly than in most other regions, and more time for penetration is permitted. This, in some measure, counteracts the effect of its imperviousness. But, in truth, the formation is so varying, in its embrace of glacial, fluviatile, lacustrine, and marine deposits, that all general statements are inadequate, and even in some measure misleading. Little more can be done here than to invite attention to the diverse influence of this most irregular surface mantle.

RAINFALL.

For the ultimate source of these fountains we are led up manifestly to the clouds, and the chief question relates to the adequacy of the supply they pour out upon the collecting area. There lurks an ambiguity, however, under the term adequacy. To what adequate? To furnish all that we can use and waste, or all that the strata may drink? The amount that may be desired is diverse in the highest degree, embracing the moderate needs of the farmer for his kitchen and cattle, the larger service of the manufacturer for his different uses, the great consumption of cities for their baths, sewers, lawns, and streets, and the almost limitless demands of irrigation. If there were no limits to the available supply it would be difficult to set bounds to the drafts that would be made upon it. On the other hand, the amount which the strata can drink in, carry underground, and deliver through the well has much more definite limits; and this is clearly the better standard by which to judge the adequacy of the rain-fall, for when it has furnished to the strata all that they can take and deliver, it can do no more. It is adequate to the existing conditions, if not to our possible desires. Any failure to yield more is chargeable to the earth and not to the sky.

Still, in the absence of a full knowledge of the subterranean conditions, the possible competency of the rain-fall may be considered.

Contrasted ratios of supply and demand.—Very generous or very meager possibilities will result from computation, according to the region put under estimate and the want to be supplied. In the more humid districts the wants of the land are satisfied and the artificial demands are limited chiefly to domestic and sanitary uses. The supply is great and the demand small. In the more arid regions the land is thirsty also, and there is an enormous demand for irrigation. The supply is small and the demand great. So, unfortunately, the greatest demand and the least supply are mated.

The ratio of rain-fall to domestic needs is usually high. There falls upon every 50 feet square in average habitable regions more than the highest *per capita* allotment of cities, even under a Parisian régime. But the ratio of rain-fall to agricultural demands, though sometimes high, is often low. The precipitation upon the 50 feet square falls far short of furnishing food-support for an individual. The shadow of an ox covers half space enough to collect the water he drinks, but it would be a very partial supply for the sward he grazes.

While, therefore, in humid regions the rain-fall, considered apart from loss, is usually ample for the demands which there commonly arise, a little inspection shows that in arid regions it is quite inadequate for the demands which *there* arise.

IRRIGATION BY ARTESIAN WELLS.

Artesian wells do not manufacture water. They do not even bring to the surface more than goes down from the surface. The total water supply of any given region is not, therefore, increased by them. They merely pour out at one point what has fallen and sunk elsewhere. If the total fall is inadequate to the agricultural wants of the total region, artesian wells cannot make it adequate. They may concentrate a sufficient supply upon a part but cannot supply the whole.

If the rain-fall of a district is but half what is necessary for agriculture, only half of it can be cultivated; but even to do this the entire quantity that falls upon one-half must be transferred to the other. This is quite impracticable, for if the agencies of both surface and underground streams were perfectly combined, there would still be the large loss from evaporation. The inadequacy of artesian wells under these conditions is apparent.

Artesian wells do not, and in the nature of the case cannot, collect their supplies from the whole face of the land, but only from the surface of the outcropping edge of the porous stratum. This usually occupies much less space than the country under which the stratum lies, and which would draw upon it for an irrigating supply. This holds true also of groups of porous beds that may underspread a given region. Now, when, bearing this disproportion of areas in mind, it is further considered that evaporation and surface drainage dispose of a large share of the rain-fall, and the wells must fail to deliver all that enters

the strata, it is manifest that only very temperate hopes can be built on this as a resource in irrigation under conditions of high aridity.[5] We must not, however, overlook some compensating conditions.

1. *Equalization of supply.*—The porous stratum acts as an equalizing reservoir. The water runs in spasmodically, according to the varying rain-fall. It is delivered with much uniformity. The extra precipitation of wet months is thus distributed over the dry. In situations in which only a small supplementary amount in the dry months is needed this equalization may be made a serviceable feature.

2. *Supplemental reservoirs.*—As the water is needed for irrigation only during the productive months, while the flow is perennial, local reservoirs may be filled in the non-growing seasons, and used when needed. This does not essentially differ from the reservoir system as applied to surface streams, save that it has advantages in localization, security from floods, and ease of control. Both are limited by their expensiveness.

Quite a small rain-fall would suffice for crops if it were utilized to the best advantage. Deluging showers, seasonal floods, and winter rains are wasteful dispensers. If the rain-fall of the dry western regions could be distributed so as to be most serviceable, the unproductive tracts would be reduced to very narrow limits. In so far as artesian wells can be made to subserve this better distribution they are a valuable aid.

3. *Advantageous transfer.*—The porous beds beneath a dry tract may receive supplies from a more favored district. Often the upturned edges of the beds form the foot-hills of mountainous ranges, which are condensers, and receive a notably increased precipitation. Artesian streams, springing from beds thus favorably situated, become a means of transfer from more humid to more arid tracts, and, to that extent, tend to equalize the distribution in space, as they have before been shown to do in time. The draft upon the source has little prejudicial effect there, while it is a boon to the more arid district.

4. *Reutilization of the water.*—When water has once passed through the soil into the strata below, its agricultural usefulness is largely exhausted, until some agency again brings it to the surface. It is not entirely useless, for, by saturating the deep beds, it prevents succeeding rains from penetrating so far as they otherwise would, and, by thus arresting them nearer the surface, retains them in a more favorable position for utilization by capillarity and deep-root penetration. But such utility is limited, and at best small, compared to the advantage that

[5] This has been well argued by Dr. C. A. White in "Artesian Wells on the Great Plains," North American Review, August, 1882; also Report of a Geological Commission appointed to examine a portion of the Great Plains east of the Rocky Mountains, and report upon the localities deemed most favorable for making experimental borings, Department of Agriculture, Washington, 1882, C. A. White, Samuel Aughey, and Horace Beach, commissioners.

might be gained by returning the water to the surface and redistributing it to the vegetation. It is clear that the greatest agricultural utility will be gained by continually bringing back to the soil the water that tries to run away, either on the surface or underground. In a perfect utilization there would be no streams, either above or below ground. The rain-fall would be absorbed by the soil, and thence by the plants, and by them returned to the atmosphere, the only loss being the inevitable evaporation from the moist soil. Of course, other valuable uses of water would thus be sacrificed to gain the highest agricultural utility. Now, artesian wells bring back to the surface water that had reached an unavailable depth, and permit it to be used a second time, to the advantage of both vegetation and the atmosphere, into which it is evaporated. There is in this an actual gain in utility, not a mere transference. There is, indeed, in some small measure, a greater total gain in using artesian than river water for irrigation, since the latter, in any case, aids by evaporation and lateral percolation, while the artesian stream is buried beyond use beneath impervious strata. These considerations urge as large a development of artesian wells in arid regions as practicable. While it is useless to think of them as a resource competent to restore productiveness to the total dry area, or even any great percentage of it, they form one of several means for its amelioration, which, when together brought into action, will react upon the climate in some measure, and, through it, feed their own sources. If the great volumes of water which the Colorado, Columbia, Missouri,[6] and other streams, above and below ground, bear away from the arid provinces could be led out upon the thirsty plains, absorbed, and given again to the atmosphere, very notable direct and indirect benefits would follow. To hope to accomplish the whole of this is doubtless utopian; certainly, to compass any great measure of it by artesian wells is chimerical, but it is none the less important to do all that is possible now, hoping, through the aid of its reactive results, to reach larger benefits in the growth of the future.[7]

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[6] Professor Powell has suggested that the utilization of the Missouri and other detritus-laden streams in irrigation would furnish at least a partial solution of the serious engineering problems they present.

[7] The State engineer of California reports, among other interesting facts, that 1,800 acres are irrigated by artesian wells in the counties of Los Angeles and San Bernardino. Nearly the maximum possibilities seem, however, to have been reached there, and although similar wells have been obtained in the great valley of California, we are not encouraged to think they will yield very great aid. (Rep. State Eng., Part IV, 1880. W. H. Hall, State Eng.; J. D. Schuyler, Asst. Eng.)

The Government commissioners above named give some of the results of attempts to secure artesian water on the great plains in the report previously cited.

Miss C. A. Salisbury, a teacher of Denver, informs me that a considerable number of successful wells have recently been sunk in that city, and that others are in progress. As yet no appreciable interference has been noticed.

Information from Hon. Horace Beach and others, as this is going to press, indicates that the number is approaching one hundred.

ADEQUACY OF RAINFALL MEASURED BY CAPACITY OF STRATA.

Let us now return from the general limitations that relate to the competency of rain-fall, in its totality, to the more practical question of the relations of precipitation to the water-carrying capacity of strata. Any surplus beyond what can be drawn through the strata, however valuable otherwise, is no aid to the artesian yield. Let us seek a condition of equilibrium for our starting point. Let it be assumed that, under the collecting area, the water in the porous stratum stands at any given depth. If this is not high enough to give a flow at some favorable point in the distance, the case does not fall within our province, the rain-fall being wholly inadequate. Let the rain-fall be a little less meager, so that some head is gained. A well opened at the proper point will draw upon this supply in proportion to the facilities for subterranean passage. If these are free and open, a sufficient number of wells may entirely draw off the head and stop the flow from exhaustion. The remaining water will stand in equilibrium. Taking this as a base level, let us consider the effect of various stages of increase in the rain-fall. For a time every increase of the rain-fall will directly augment the flow. The ratio of increase of precipitation and flow will remain nearly equal until the facilities for traversing the strata begin to be taxed. If precipitation be increased beyond this, the first effect will be to raise the head. This will increase the force by which the water is pressed through the stratum, and augment the flow, but in a diminished ratio. Every further increase of rain-fall will add to the head, and likewise to the flow, until the water in the porous bed rises practically to the surface. Beyond that point, of course, an increase of the rain-fall has little effect, for the excess flows away on the surface or is lost by evaporation.

Now, when the strata of the collecting tract are shown to be full by such overflow, we are furnished with a direct indication, not only of a competency of rain-fall, but of, at least, some surplus. Herein is afforded a practical means of determining conditions, previous to actual trial by boring. The average height of the common water-level of the collecting area, as shown by wells, measures essentially the elevation of the fountain-head. If great fluctuations are produced in these by varying rain-fall, a corresponding effect will be felt by the proposed wells. But, if they are essentially constant, the element of precipitation may be assumed to be already high enough to lend its best aid; for stability is not likely to arise from any other cause than a surplus, regulated by an overflow. If this is not apparent, let a surface lake be taken as the representative of the underground one. Lakes which have no outflow are raised by rain-fall and lowered by evaporation and percolation, and of course fluctuate with dry and wet seasons. Those which are well fed and have an outlet, are nearly constant, for the obvious reason that the inflow will supply loss from evaporation and percolation in dry seasons, the overflow being slackened, while the overflow will draw off the surplus of wet seasons, being increased to meet the demand. The fluctuations

are, therefore, confined to the few feet necessary to adjust the discharge to the surplus. So when the subterranean water-body has no outflow, except percolation and evaporation, through capillarity, it must grow with the increase of rain-fall and shrink with its decrease; but when fed to overflowing its surface is kept constant by the discharge of the surplus. Constancy in the level of a lake, amid changes of rain-fall, points clearly to an adequate supply and a regulating outflow. So constancy in the surface of the subterranean accumulation is a sign of a sufficient supply and an overflow of the surplus. In this case, to be constant, is to be full.

There is also a rude index of the surplus in the water, which, having been once absorbed into the upper edge of the porous bed, issues again in springs. If the porous bed were not already full, we must conclude that the water would descend into it and remain. It only comes forth because the stratum, being full, cannot admit it. Water may be shed from the surface while the earth below is still not saturated; but, having once entered a continuous porous bed it can only be assumed to re-issue because it cannot penetrate deeper.

These indications show the *existing conditions* of the supply, whether the stratum has been tapped or not, and serve as a guide for the next following enterprises. If, with additional wells, springs in the collecting tract dry up, and the water level sinks, without other assignable cause, there is reason to apprehend that the draft is being felt at the fountain-head in the consumption of the surplus, if not in the reduction of the reservoir.

Accepted with qualifications, the general judgment may be expressed that in regions which have sufficient precipitation for successful agriculture, the atmosphere pours upon the upper edge of the porous strata all that distant wells are able to draw through them. There will be some exceptions where enormous drafts are attempted under conditions exceptionally favorable for the exhaustion of the supply. But these are cases in which special study of all the conditions should be made before the enterprise is undertaken. There may be exceptions, also, when the carrying capacity of the porous bed is very great, while the collecting area is limited. But the general statement is fairly reliable in its application to the usual undertakings of citizens and corporations.

In that class of wells that are derived from the drift, or other local unconsolidated surface beds, more variation is experienced, and a closer relationship to the full measure of precipitation is observed. For in these (1) the beds of passage are usually open layers of sand and gravel, which permit a free flow of the water, (2) the reservoir is near at hand, so that the resistance between it and the well is small, and (3) the collecting area is usually limited. Under these conditions a large number of capacious bores may easily draw off all that the rain-fall can supply to the limited collecting area. Hence the amount of flow will fluctuate somewhat closely with the amount of rain-fall.

The cases in which an increase of rain-fall beyond a certain moderate amount will be most markedly felt are those in which the conveying capacity of the water-bearing bed is great, and the restraining power of the overlying beds imperfect. But if the water-bearing bed is close-textured and the cover-beds water-tight a moderate rain-fall will furnish to the collecting tract more than the stratum can deliver to any practicable number of distant wells, and will maintain the head near its maximum elevation.

From the foregoing considerations it appears that in a large class of wells of inferior stratigraphical conditions the amount of the rain-fall, beyond a certain moderate measure, is nearly, though not entirely, immaterial; whereas, in the class of more generous native capabilities, it is an element of supreme consequence.

ESCAPE OF WATER AT LOWER LEVELS THAN THE WELL.

It is manifest that if the confining beds are pierced either naturally or artificially at a point lower than the surface of the well, the water may find relief from pressure by escaping there and fail to flow from the well. This is not often a source of failure from natural causes, where the overlying strata are thick, since the tendency in the deeper beds is rather toward the closing of openings and the healing of fissures than to the opening of a free passage way. However, in those regions in which profound fracture and displacement are common, failure from leakage through fissures is a source of apprehension.

The artificial defects consist mainly of wells previously sunk. It is a well-known fact that, where several are located near each other, those which are lower than the proposed well may already have consumed the full delivering capacity of the water-bed. The reverse may also happen. The new well, if lower than the previous ones, may draw off their flow. The remedy in these cases is simple. Either the flow of the lower wells may be reduced until the upper ones discharge, or else all may be brought to the same level by tubing. There is, perhaps, no better test of the delivering capacity of the water-bed than the degree of interference of neighboring fountains. In proportion as the supply is generous and freely delivered at the well, interference will be decreased. Notable interference of wells is a clear indication that some approach has already been made toward the limit of productiveness for that vicinity.

A hidden source of failure may be concealed in old deep wells, which either never were put under proper control, or which have fallen into neglect. The water may rise through these into loose superficial deposits or higher permeable strata and pass off horizontally, and thus afford relief of pressure without discovering itself at the surface. The remedy

is either to block up these old wells deep within the confining bed, or else put them under the same control as the new one.

CONDITIONS RELATING TO THE WELL ITSELF.

1. *The rate of delivery.*—It has already been made sufficiently evident that, however great the supply at the fountain-head, if the water must pass for a long distance through a thin sheet of close-grained rock, the rate of delivery at the well will be slow. If, on the other hand, the texture of the rock is open and the bed thick, the supply will be, other conditions favoring, very abundant.

A second condition of delivery relates to the well itself. It is clear that, if the bore merely touches the upper surface of the water-bearing bed, only a small space is afforded for the entrance of the stream. If, on the other hand, the well penetrates the formation deeply, the water can run in all along the sides, and, though the inflow at any one point may be moderate, the total amount from the large surface presented by the sides of the bore may be great.

Methods of increasing the flow.—*a. Torpedoes.*—Even where the entire thickness of the porous stratum has been penetrated, and all the advantages to be secured from increase of surface, in so doing, have been exhausted, the supply may still remain deficient. In some cases the yield is notably less than good reason gave encouragement to expect. The porosity of any bed is apt to be varying; and a well may be unfortunate in passing through a close-textured portion; or, if the water-bearing character is dependent on fissures and channels these may have been missed, though they may lie close at one side. In such instances an effective means of promoting a flow is found in the firing of explosives within the bore.[8] The manifest effect of an explosion is to fissure the beds extensively about the bore, and greatly facilitate the inflow. In the oil regions this device has been extensively used, and found both practicable and effective.

b. Enlarging the bore.—An obvious means of increasing delivery is an enlargement of the bore of the well. So far as this is intended to increase the surface within the porous bed, it is manifestly both inferior and more costly than torpedoing where the well is deep, but it has an obvious advantage in the larger conduit it affords for outflow. It is the practice of many drillers to first sink a well of the usual small dimensions, and then rim it out to the larger diameter desired. Besides the advantages in drilling this renders the cost of testing the chances at that point less. From the character of the flow obtained

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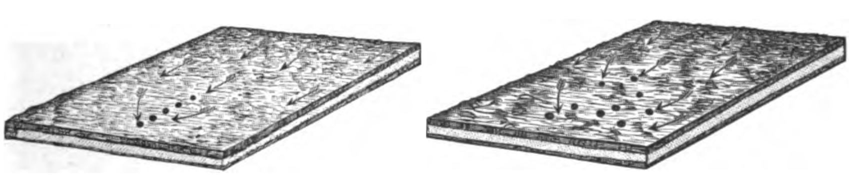
[8] Mr. John F. Carl, of the Pennsylvania Geological Survey, has given a very clear and detailed description of the construction and use of the torpedo chiefly employed in the oil regions. Second Geol. Surv. Penn. Oil Regions, III, 1880, p. 327.

by the first operation it is possible to anticipate what will be the probable result of the enlargement. If the water issues with great force, it is manifest that the larger bore will greatly increase the delivery, because, in addition to the increased size, the friction is relatively less. If the flow be gentle, and the head known to be high, it is clear that the conveying stratum must interpose obstacles, and the indications are unfavorable to a very great increase from the enlarged well. If the fountain-head is low a full gentle flow is the natural sign of a generous stream, which might give an almost equally flush discharge from the enlarged bore.

c. One large or several small bores?—In demands for large volumes of water, as in the supply of villages and cities, the alternative of one large or several smaller wells, is presented. On this question, the following suggestions may be offered. If the capacity of the water-bearing bed is known, or, from evidence, is confidently believed to be amply sufficient to pour into the base of the well all the water demanded from its mouth, so that the question becomes merely one of providing a suitably capacious delivery tube, it is manifest that, within the limits of economical drilling, the advantage lies with the single large well. But, in all cases where very large supplies are needed, and, especially, in all cases where the possibilities of the water-bed are liable to be taxed to their utmost, advantage may be derived by sinking several wells separated by intervals; for a much larger area of the productive stratum will thus be drawn upon. The vital issue, in this case, is not so much the providing of means for the water to rise to the surface, as the aiding of the water-carrying stratum in delivering it to the base of the wells. It is clear that the porous rock about the base of a single well, even though it be large, cannot furnish as great inflow as the rock about several wells, though they be individually, and even collectively, smaller. Besides, if torpedoes are used, the intake of each smaller well may be made approximately as great as that of the large one. The enormous wells that have sometimes been undertaken, are, therefore, not to be recommended.

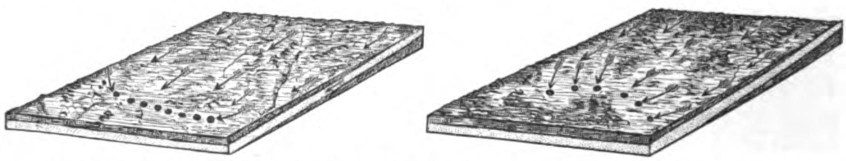
d. Distribution of wells.—In the employment of several wells their distribution is a matter of some consequence. The normal direction of flow when it is once set up by virtue of the opening of an avenue of



FIGS. 21 AND 22.—Tabular sections of strata, showing disadvantageous arrangements of wells.

discharge is along a line drawn from the outcropping edge of the bed down its slope to the wells. Now, it is clear that if several wells are

arranged along this line, the first one will be better placed than those which stand in its lee. These will be, indeed, measurably supplied by lateral flowage under the law of equal pressures, but less directly and freely. If the wells are disposed in a cluster, those on the exterior will partially cut off the supply of the interior wells. A more fortunate disposition than either of these would be an arrangement in a line at right angles to the direction of flow.



FIGS. 23 and 24.—Tabular sections of strata, showing advantageous arrangements of wells.

A still more advantageous arrangement, subject to local modification would be to dispose the wells in a curved line, convex toward the collecting tract, for when the draft of the wells has made itself felt upon the sheet of water flowing most directly from the collecting belt to them, the higher pressure, which the flanking portions still suffer, will cause a lateral inflow, and the curved disposal of the wells will be more favorable for receiving the ingathering currents than a rectilinear arrangement, being more nearly normal to the resultant pressure and flowage.

In respect to the degree of separation of the wells, it is obvious that so far as the mere question of the greatest reception is concerned the farther they are apart the better, for they will affect each other less; but, of course, practical considerations put a limit to their dispersion.

LOSS OF FLOW IN THE WELL.

Having previously considered the favorable and unfavorable conditions that relate to the source and underground course of the flow, we were led, in the last paragraphs, to touch upon some considerations relating to the well itself. Let us now come more squarely upon the topic and search for causes of retardation in the well.

1. *Friction.*—We have already incidentally referred to the fact that an increase in the diameter of the well diminishes the relative amount of friction, and that, so far as this element alone is concerned, the advantage lies with the larger wells. The introduction of a small delivery tube at the top of the well obviously increases the friction and diminishes the flow. There is an illusive impression abroad that a reduction of the size of the delivery tube will increase the height to which the water will flow. This is altogether fallacious. It perhaps arises from the fact that a reduction in the mouth of a discharge pipe may be made to increase the force of the jet thrown out; but this jet never rises so high as the water would in an open tube carried upward, and the water will rise to the same height in a large tube as in a small one.

2. *Lateral leakage.*—In being forced up, the water will flow off sideways at its first opportunity. If, therefore, at any point in the upper portion of the well, it finds a crevice, or channel, or a porous bed, which is not occupied by water under as great pressure as itself, it will escape laterally, instead of forcing the column to the surface. It is necessary to prevent this lateral leakage. Sometimes the necessities of drilling lead to a satisfactory prevention. In sinking the well through the soil, sand, gravel, clay, or other loose material that may lie above the bed rock, it is customary to force down an iron tube, and sink it a few feet into the bed rock, by using a larger bit than that employed for the rest of the well. If a good joint is made here, and the rock below is tight, the lateral leakage may be thereby cut off, but this is not always available nor usually reliable. Besides, in many instances, the upper beds permit much waste, and recourse must be had to special methods for its control.

3. *Control of flow.*—It is clear, upon consideration, that perfect control may be obtained by putting down a tube to the densest portion of the upper confining bed, if, by some device, the space surrounding it may be closed up, so that no water can rise outside of the tube. Formerly, this was done by a very simple and ingenious device, known as the *seed-bag*. A long, stout, leather bag is made in the form of a cylinder, open at both ends, and just the size of the well-bore. This is slipped on the lower end of the pipe, and the bottom of the bag securely fastened about the tube by wrapping with marline. A thimble just above the tie will aid in preventing slipping. It is then filled with dried flax-seed, and the upper end likewise closed around the tube. When thus adjusted it is lowered into the well to the point determined upon, and supported there until the seeds swell by absorbing water. This enlarges the bag so as to fit the bore tightly and shut off all water from rising outside the pipe, and so all is compelled to ascend through the tube to the surface, or, at least, as high as the pressure is competent to force it.

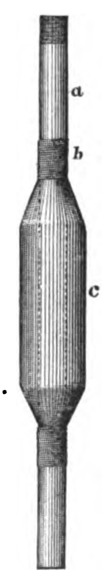


FIG. 25.—Seed-bag: *a*, delivery tube, leading to the surface of the well, and terminating below the seed-bag; *c*, a leather bag filled with dry flax-seed; *b*, marline wrappings to secure the end of the seed-bag.

A better and more convenient, but more expensive, packing takes advantage of the expansion of rubber disks when pressed together, instead of the swelling of flax-seed. A series of thick, washer-like rings

of rubber are fitted about a section of pipe, so adjusted between iron disks that, after being put down, they can be screwed together, and so caused to expand laterally, and completely fill the bore.

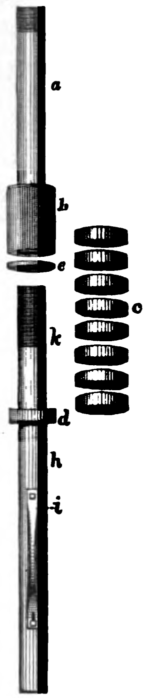


Fig. 26.

Fig. 27.

FIG. 26.—Rubber packing, shown apart; *a*, section of delivery tube, extending to the surface; *b*, a large thimble into which *k* screws; *e* an iron washer; *c*, a set of rubber disks, fitting on *k*, between *b* and *d*; *k*, a section of pipe on which is turned a long screw fitting in the thimble *b*; *d*, a disk forming the head of the screw *k*; *h*, a section of pipe extending about two feet below the packing; *i*, a spring to press against the walls and hold the pipe *h*, while the section *a* and thimble *b* are screwed upon *k*.

FIG. 27.—Rubber packing, shown screwed together as it is in the well.

The construction of the parts and their adjustment are sufficiently indicated in the accompanying figures, which illustrate one of the forms in use.

In a form employed in the oil regions, the expansion of the rubber disks, or single cylindrical one, is accomplished by pressing a conical hollow wedge between the pipe and the rings, thus forcing them out against the walls of the well.

In this case the packing is supported by a perforated tube, an "anchor," reaching to the bottom of the well. As the packing in artesian wells is often located near the top, the necessity for support from below excludes this form in most cases.[9]

[9] This form is described and figured by Mr. Carl, Second Geol. Surv. Penn.. Rep. on Oil Regions, III, 1880, p. 322.

HEIGHT OF FLOW.

1. *Measurement.*—When the flow has been confined to the tube by either of the above devices, it is an easy matter to determine the available height to which it may be carried. Where the pressure is moderate, this is easiest determined by adding pipe above the surface until the water no longer rises through it. But when the pressure is great, it would ascend to an inconvenient height, and a pressure-gauge of any available form may be substituted, and the height to which the water would rise, if suitably tubed, computed; each pound of pressure per square inch equaling 2.31 feet of rise.

2. *Prognostic estimate.*—The testing of the full strength of a generous fountain, already secured, is a comforting task, quite in contrast to the solicitude one suffers in attempting to estimate beforehand what height may be anticipated. Theoretically, the water will rise at the well to the same height as the fountain-head, and will flow at any elevation less than that. But the leakage of the confining strata and of the well reduce the height to which the water will rise, while the friction suffered in the long passage through the rock and the well will further lessen the altitude at which flow, of any notable vigor, will take place. Deduction must be made for all these elements. The special conditions which affect the estimate have been previously considered.[10] All the light that can be drawn from a careful scrutiny of these is demanded. The prudent expert will, however, seek assiduously a better and more truly scientific basis for his judgment. In almost every district wells have been attempted, and their results—whether successful or otherwise—if critically analyzed and interpreted, give valuable data, even though somewhat removed from the locality under consideration. The importance of recording and preserving the precise results of all enterprises, whether good or ill, cannot be too strongly urged upon drillers, geologists, and citizens alike, nor is it, perhaps, out of place here to urge that an intelligent respect be paid to the facts so developed; the respect, however, is no more important than the intelligence.

DETECTION OF FLOW.

It has been remarked above that the water may rise from the bottom to some higher portion of the well, and there find escape by passing off laterally through the upper strata. In the absence of control, the water does not always rise and overflow. It is a matter of some practical moment, therefore, to know when a stream is struck which may yield a flow at the surface when put under proper control. (1.)

[10] These conditions are so varied that I doubt the propriety of attempting any general statement of the deduction to be made from theoretical height. For Southern Wisconsin, I have found an allowance of about 1 foot for every mile between the collecting area and the site of the well to be as near a general estimate as I feel prepared to make; but even this is subject to considerable modification in special situations, and could not safely be adopted for other regions.

Such a stream usually discovers itself by a rise of water in the well, but this is not always the case. (2.) Some influence on the action of the drill is liable to be felt, which may arouse suspicion. (3.) In any instance of a strong flow, the drillings are apt to be carried away, so that when the sand-pump fails to bring these up, or brings only coarser material, there is good reason to believe that a stream has been struck, and the proper tests should be made. In enterprises that do not require a voluminous flow, tests should usually be made when such indications appear. It is ordinarily desirable to test the capacity of any stratum which gives any of these or other indications, before sinking to a lower one. It is advisable to make provision in the contract for such tests, since it is not always to the interest of the driller, once his machinery is set up and well at work, to stop at the more limited depth. The capabilities of the flow may be tested by the use of a tube and seed-bag, or by rubber packing, as explained above.

Negative and false tests.—1. It is possible, in perfect honesty, to make both a negative and a false test. Suppose that two porous beds, A and B (Fig. 28), separated by an impervious layer, are traversed, and the testing of the first has been neglected, either because it failed to give encouraging indications or for other reasons. It is now desired to test these. Suppose the seed-bag or rubber packing be placed above the upper one. Now, if both bear a water-level equally high, the test will be fairly made, and the result will indicate their combined capacity; or, if both heads are at least as high as the surface at the well, the test may be accepted. But suppose that the bed A has been cut into by erosion, or been reached by crevices, or is otherwise defective, while the other, B, remains intact and bears an elevated fountain-head. Under these conditions the water may flow from B through the bore into A, and escape laterally through it, as illustrated in the figure. Now, in this case the result may be either simply negative or positively false and misleading. If the lateral leakage through the stratum A effectually disposed of the flow from B, and there was no leakage in the upper portion of the well, the water in the test-tube would stand during the test at essentially the same height as before, and the result would be negative, merely failing to indicate a possibility that really existed. If, on the other hand, there was lateral leakage through the upper strata as well as through A, neither alone being quite competent to dispose of the flow from B, then the introduction of the test-pipe would cut off the upper leakage, leaving the bed A unable to dispose of the entire flow. In this case there would be a rise of water in the tube, and, possibly, a flow. The mischievousness of a test of this sort lies in the fact that it

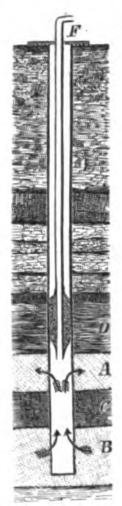


FIG. 28.—Section of a well, illustrating a negative test.

appears to be a true test, because it shows some result, while in reality it is false and misleading. The true test in this case can only be made by placing the packing between the porous beds A and B.

2. Take another instance where two porous beds, as A and B, figure 29, have been traversed. Let the packing be placed between these. Then (1), if A equals B in productive capacity, water will stand at the same height within and without the test-pipe *if there is no leakage in the upper beds.* (2) If the failure to flow was due to such leakage, then a flow will result from B, but the additional flow which might be secured from A is lost (see figure). (3) If A has a greater head than B, and if there is no loss above, the water in the test-pipe will actually be lower than that outside, as illustrated in figure 30. This may be said to be an *inverted test*, and is less misleading than the false and negative tests, since it plainly indicates an error of manipulation. I have known such a case of reduced head as the result of an attempted test. (4) If, however, there is in this case considerable lateral waste in the upper strata, the valuable flow from A will be lost, just as before the test was made, while B may give a rise in the tube, or even a flow, which would foster the impression that a fair test had been made, while in reality the greater flow has been lost. (5) If A gives a feebler flow than B, but has an equal head, the test will fail of being completely satisfactory only in excluding the feebler flow from A. (6) If, however, A has a lower head, and is a possible means of escape for the flowage from B, then the packing has been placed at the right point, and the test gives the best results.

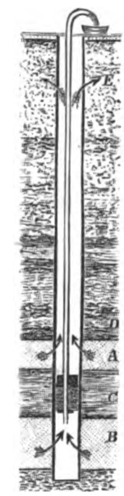


FIG. 29.—Section of a well showing a partial and misleading test.

3. In still another case let A and B represent porous beds (figure 31), the lower of which is so conditioned as to drain the upper one by virtue of a lower outcrop, in the manner previously explained and illustrated in figures 13 and 14. (1) First, if the drainage-loss below is not complete, and if the packing is placed above A, as shown in figure 31, I, the result will be negative, if there is no leakage in the upper strata. (2) Should there be considerable loss there it will be cut off by the tube and packing, and some rise in the tube will be the result in most cases. In either instance the result is misleading, particularly in the last, because the small

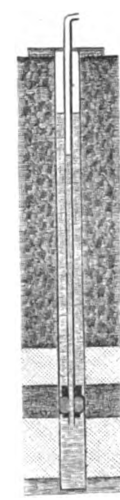


FIG. 30.—Section of a well illustrating an inverted test.

rise of the water is apt to allay any suspicion as to the effectiveness of the test. The real fact, however, remains that the flow from the productive stratum is mainly lost below. (3) Suppose that the packing is located between A and B, as in figure 31, II, it will then shut off the flow from A, while that in B, because of a lower outlet, will fail to flow. Now, if there is opportunity for lateral leakage in the upper strata the water from A will rise in the well *outside* of the test-pipe and pass off into these open upper beds. (4) But if no such opportunity is afforded it may rise to the surface and overflow *outside* of the test-pipe, while the water within the test-pipe will probably be found to be lower than

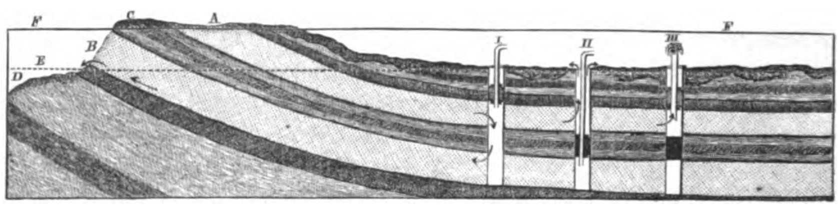


FIG. 31.—Section of strata and three wells, showing one correct and two erroneous tests. These wells are assumed to be independent of each other, and are placed together on the diagram merely for convenience.

before the test was made. The proper method of testing wells known or suspected to present these conditions is to sink a simple bag of seed or other obstruction to a point in the impervious stratum between A and B, which, when it tightens in its place, will shut off the flow below. Then a tube with packing sunk to a point above A will effectually cut off all leakage in the upper strata, and the full capacity of the water-bed A will be tested.

These examples, while not exhaustive of possible cases, illustrate the nature of defective tests and the deceptive conclusions liable to be drawn from them. The remedy is manifest. Test each water-bearing stratum as it is encountered, or else vary the final tests so as effectually to exclude all liabilities to error.

EFFECT OF TIME ON FLOW.

It is a common observation that the discharge of artesian wells declines in time, and the impression has somewhat obtained that this general fact is a necessary one. It is not unimportant, therefore, to consider the causes that lead to decline, since this is likely to be the best approach to the vital question, whether it is inevitable or preventable.

1. *Decline from loss of gaseous aid.*—We have thus far neglected a class of wells which flow, not from the pressure of an elevated fountainhead, but from the expansive force of pent-up gases, which are either disseminated throughout the water itself, like the carbonic acid in the soda fountain, or are contained in some hidden reservoir in communication with the water which is thus forced out. Wells of this class ejecting petroleum, gas, and water are familiar features of the oil regions.

A well whose flow arises from any such cause must decline as the gas relieves itself by escape, unless it is continually renewed by generation below, which is doubtless very rare. But while this class of wells lies without the province to which we are limiting ourselves here, it illustrates strikingly a cause of flow which has some little exemplification in the wells under consideration. Most waters that have stood pent up in the depths of the earth contain, absorbed within themselves, a greater or less amount of carbonic acid and other gases. When relief reaches these by the penetration of the well they expand and aid in lifting the column, both by their elasticity and levity, so that when first struck the water frequently flows with a sparkling vigor not permanently retained. Gradually the pent-up gas relieves itself and the flow correspondingly declines. The main effect of this, however, is doubtless brief, and so far as this element is concerned the flow settles down into an essentially stable current.

2. *Decline from loss of heat.*—An exceedingly slow, and almost infinitesimal decline may be assumed to result from a change of temperature. The water entering at the fountain-head has about the average temperature of the region. That issuing from deep artesian wells is warmer by several degrees. This relative warmth by lightening the column aids, in some little measure, the flow. The heat is derived from the deeper strata which the artesian current traverses, and manifestly they are continually losing what the stream is continually gaining, and a slow process of cooling the strata is going on. The temperature of the current must decline accordingly, and the aid derived from the warmth be correspondingly lost. This decline is probably much too slight and too slow to be of practical moment, though I am not aware what observation may teach on this subject, if, indeed, it has received attention.

3. *Decline from increase of leakage.*—Reference has previously been made to the disposition of the water as it rises in the well to find lateral escape through the upper strata. It is, of course, the intention of the well-sinker, in putting in his final delivery tube and packing, to cut this off by lowering the pipe to a point below which this does not take place. But, being expensive, it is not inserted deeper than thought strictly necessary. Now, many beds permit lateral leakage in a feeble degree, which are yet in the larger sense impervious, as, for example, many of our limestones. The lateral leakage which they permit may be at first imperceptible, but under the high pressure, minute streams thread their way through the tiny openings in the rock, and, little by little, by virtue of their wearing and solvent action, increase their channels until at length, through their united influence, they make themselves felt upon the greater stream. In many cases there are some hundreds of feet of limestone exposed to this action beneath the packing.

Again, since the packing occupies, at most, but two or three feet in the bore, the water, pressing from below, may thread its way around it

through the capillary passages, and, at length, by enlarging these to more considerable dimensions, find partial relief in that way.

It is evident that both of these sources of leakage may be corrected by inserting the tube and packing to a lower point.

4. *Decline from closure of the bore.*—It is a well-known fact that some rock-beds, under great pressure from the strata above, "creep" toward artificial openings, such as the shafts and drifts of mines. So small a perforation as a well-bore, with its walls arched against an inward yielding, and filled with a column of water exerting from one-third to one-half as much pressure as the rock, does not invite this action. But some beds are soft and plastic, as the clays and clay-shales, while other are loose and mobile, as the sands and half coherent sandstones. Beds of these kinds, at considerable depths, where the pressure is severe, may yield, and tend to close the bore. Of course, the friction of the current is increased by the assumed stricture, and tends to cut it away, but perfectly pure water has little corrasive power. In the more stable formations it may be doubted whether this is often an occasion of decline. In the newer and less consolidated beds it is to be apprehended that it is. Closure of this kind could be tested by lowering an expanding gauge through the delivery tube; and it could, probably, in most cases, be successfully rimmed out with an expanding drill without removing the tubing.

Closure may also arise from an accumulation of sand and other fine matter brought into the bore by the inrushing current.

5. *Decline from defective piping.*—Obviously, growing defects in the tubing and packing would favor decline. Iron piping rusts rapidly, especially if there are corrosive ingredients in the water. If the decline sets in only after a few years, and rapidly increases, suspicion points in this direction.

6. *Decline from exhaustion.*—The too current notion that a subterranean pool, which has been struck by a well, supplies it for a time and then becomes exhausted, may be dismissed without much consideration, for no such pool will be apt, under existing hydrostatic laws, to leave its deep-seated repose and pour itself out upon the surface merely because an opening is provided. If forced by a distant head, that head may be drawn down, but the pool will remain as full as ever. I can conceive of nothing but the collapse of the inclosing walls that could force it to evacuate, and that would give a violence of ejection and suddenness of cessation corresponding to the rate of collapse, a phenomenon quite different from that commonly referred to the exhaustion of a subterranean pool. The exhaustion is not in the imagined pool under the well, but in the distant elevated edge of the water-bed. If there is but a limited accumulation there and it is not promptly renewed from the surface the well may gradually draw it off. In doing this, it is obvious that the head is, little by little, lowered, and hence has less and less forcing power. The flow, therefore, declines gradually. A decreas-

ing flow from this cause will fluctuate with the rainfall upon the distant collecting area, and will renew itself with returning wet seasons. A decline followed by a permanent refusal to flow points to some other cause. Decrease of flow due to overdraft on the supply, or exhaustion of the fountain-head, has a more adverse promise than those previously noted, since it is, in the main, irremediable.

7. *Detection of the cause of decline.*—From a consideration of the preceding causes of decline I venture the suggestion, without knowing from experience how far it may be practicable, that the precise way in which the decrease takes place may give a clew to the cause. The decline from exhaustion of stored gases should set in early and proceed rapidly for a time, and then more and more slowly as the exhaustion of the gas proceeds. That from heat may be neglected. That from enlargement of capillary pores would set in tardily and increase slowly, and at length probably produce a total stoppage. That from rusting of pipes, or decay of packing would not be felt at all at first, and would probably increase rapidly when once started, until an entire cessation ensued. That from closure of the bore would be slow in coming into action, if due to the "creeps" or filling, but if due to caving, it would be sudden and probably complete. That from exhaustion of the fountain-head would be gradual and decreasing, and its flow would be renewed with every fresh atmospheric supply.

CHARACTER OF THE WATER.

1. *Temperature.*—It is a well-known fact that the temperature of the earth increases as its interior is penetrated at an average rate of 1 degree for every 50 or 60 feet, and that waters arising from the deeper strata partake of their elevated temperature. The water of the celebrated well at Grenelle, near Paris, has a temperature of 82°; that of Saint Louis, 73°.4; that of Louisville, 76°.5; that of Charleston, 87°. When the temperature is notably above 70° it may be rendered serviceable as a source of heat. The hospital of Grenelle is said to be heated by the famous well of that place. Below the temperature suitable for this purpose the warmth renders the water less immediately palatable, but facilitates its distribution through pipes in cold weather by preventing freezing.

2. *Chemical impregnations.*—The water which descends from the clouds is nearly free from mineral ingredients. As it penetrates the earth, it gradually becomes mineralized by dissolving the soluble constituents of the strata. The extent to which it thus impregnates itself is, among other things, dependent on (1) the character of the soil and rock through which it percolates, (2) the depth which it penetrates, and (3) the time it remains confined within the earth. It

is not strange, therefore, that waters rising from great depths should frequently be mineralized in a notable degree. The saline combinations may be various, but the constituents are but the soluble ingredients of the strata. When these constituents are such as to impart to the water undoubted hygienic and remedial properties, there may be no occasion to regard this impregnation as unfortunate. But when considered with reference to common domestic purposes, the mineralization of artesian water is a condition of debatable value. For drinking purposes, a moderate mineralization is, on the whole, probably beneficial, rather than injurious, though authorities are not entirely agreed upon this point. For laundry uses, the property of hardness, usually communicated by lime and other salts, is objectionable and the incrustations deposited upon boilers detract from its serviceableness to manufacturers. It is usually, though not universally, harder than the river and lake water of the region. In all cases, where city supplies are contemplated, opposing preferences are apt to arise, when the choice lies between artesian water on the one hand, and lake or river water on the other. Those to whom purity is a supreme consideration, whether it be freedom from infectious germs, deleterious organic solutions, or mechanically-suspended sediment, lean strongly to an artesian supply. With those who, neglectful of these considerations, are more influenced by industrial utility, a surface supply usually commands preference.

To the general rule, that artesian waters are more impregnated with mineral salts than surface waters, exceptions are found in those cases in which the rain-fall directly penetrates sandy soil, and thence passes on at once into an open stratum of quartzose sandstone, from which, without penetrating deeply, or remaining long within the earth, or coming in contact with calcareous beds, it is brought again to the surface. Such waters are often notably soft and relatively free from mineral impregnations.

There seems to be sufficient evidence to justify the statement—in itself very rational—that the water of an inclined stratum increases in mineralization with its depth and distance from the outcropping edge. At the upper margin, it is only rain-water, filtered through the soil, which has already been subjected to much leaching, which is, indeed, often little more than the insoluble residue of disintegrated rock. As it penetrates farther, it increases the earth-material with which it has come in contact, and is commingled with waters that have slowly percolated through the capillary pores of the adjacent strata, which, being relatively impervious, are as yet but partially leached of their oceanic salts, much less their rock substance. Manifestly, the farther it penetrates, and the longer it remains imbedded in the deep strata, the more mineral matter it has opportunity to dissolve from them.

Now, on the first opening of an artesian well the waters rising from the depths are possibly such as have long remained within the strata from want of any other means of exit than the slow methods of diffusion

and capillary penetration. But, on the opening of a generous outlet, these pour forth upon the surface, and those that flow down from the fountain head to take their places pass less slowly through the stratum, and, presumably, are less impregnated with mineral ingredients. In the lapse of time the track of the current must become relatively more leached of its soluble constituents than portions impregnated with more nearly stagnant water. Hence the progressive tendency of artesian water is toward less mineralization. Whether the amount of this reduction is of practical consequence, has not, so far as I am aware, been satisfactorily determined by careful observation, but the impression that the water becomes gradually purer from extraneous matter is a not uncommon one.

LIMITS IN DEPTH.

The vitality of a false notion is often surprising. It is sometimes crushing to our faith in the survival of the fittest. A striking illustration is found in the wide-spread popular delusion that an abundant flow may always be found "if you only go deep enough." When we consider that rain-fall is the great source of the waters of the land, and that the strata, as a rule, become more compact as depth increases, it is apparent that a very nearly opposite presumption should displace this fallacy. It doubtless arises from the fact that the immediate surface beds are more or less dry, and that it is necessary to penetrate some small distance to reach the subterranean water-bed. It is not realized that when this is once fairly reached the most richly supplied aqueous horizon is found. The beds below grow closer in general, and present less opportunity for accumulation. If, in imagination, the relatively dry surface were removed the rest of the earth might be conceived as most copiously filled with water in the more open upper portion, and less and less permeated below, because less and less open to receive water. This is, of course, only a general law, subject to much modification, according to the kinds of rock which overlie each other in succession.

In view of this general presumption, it is folly to sink deep wells without some definite knowledge that a rock of porous nature lies below and presents the requisite conditions for supplying a fountain. The occasional luck of ignorance may find a flow, but it is not soothing to our pride of popular intelligence to note how thickly our land is punctured by needless follies, largely encouraged by the above fallacious conception.

Preliminary to sinking a well, as complete knowledge of the underlying strata as it is possible to obtain from the usual methods of geological inquiry should be gathered, and the depth of the well limited to that necessary to reach the most productive stratum. To be sure, there

are regions in which, in the absence of specific knowledge, or when such as can be obtained is indecisive, the sinking of a deep well to test the strata is warranted by the importance of a favorable result; but the uncertainties of the issue and the financial hazard of the undertaking should be frankly faced. It is not to be inferred from these conservative remarks that failures do not result from the opposite cause, that wells do not often come short of success by stopping short of the proper horizon. The existence of such failures only adds to the importance of specific knowledge in lieu of broad proverbs and loose maxims.

The succession of strata is so various in different regions that general rules are few. There is one, however, of wide application whose observance would save the useless expenditure of large sums. The Archæan rocks, as before observed, are exceedingly unpromising of success in themselves, and do not overlie productive beds. Whenever, therefore, in the progress of drilling these are struck, work should cease, unless there are specific local facts warranting a deviation from the rule. A provision to this effect should be inserted in all contracts, since it is in the interest of both parties, for the drilling is usually very difficult and unremunerative at any ordinary rate per foot, while, there being no rational prospect of good results to the owner, the amount he pays, however unremunerative to the driller, is a dead loss to himself. It is not sufficient to insert the term *granite* instead of *Archæan rock*, as is sometimes done, since quartzites and other crystalline rocks, not fairly embraced under the term granite, even in its more extended sense, are included in the Archæan series, the penetration of which would prove alike unprofitable to driller and owner.

Locally there are other formations at which drilling should cease, either because no productive beds occur below, or because they are known to lie at unavailable depths. Specific knowledge of such local conditions is requisite for guidance in these instances.

THE ART OF SINKING WELLS.

It does not fall within the proposed scope of this article to enter upon a detailed discussion of the art of sinking wells, of the difficulties encountered, and of the ingenious devices by which they are overcome, but a few general statements may not be without interest in themselves, while they lead the way to other topics whose discussion is more imperative.

1. *Superiority of methods in the oil regions.*—Were it within our province to discuss the art of drilling, it would be necessary to go beyond the field of artesian wells proper to find its highest development; for whatever may have been the result in other respects of the traditional strife between water and oil, that never agree, the latter has

proved itself the master as an incentive to the development of ingenuity and skill in the art of drilling. The innumerable practical difficulties that rendered the earlier attempts tedious and hazardous at the best, failures often, have been largely mastered, and the sinking of wells one or two thousand feet deep is now a daily successful occurrence. To the oil regions, therefore, we must turn for the finest examples of technical skill in this art. For an exposition of this development, detailed with much particularity, and accurately illustrated, I can refer to nothing better than the report of John F. Carl, on the Oil Regions of Pennsylvania.[11]

The methods of sinking artesian wells in common use, are either slight variations from those current in oil regions, or represent some of the earlier methods in leading up to the present stage, and which remain serviceable for the less exacting demands of the shallower wells. All are modifications of the ancient chisel drill, which, by being lifted and let fall, cuts its way into the rock, being at the same time rotated to keep the hole round, uniform, and vertical.

2. *Use of the diamond drill.*—To a limited extent, the diamond drill has been employed. It is essentially an iron tube, armed at its lower extremity with cutting diamonds so placed that when rotated the tube cuts its way into the rock, leaving a cylindrical core in the center. A current of water, forced down the interior of the tube, and rising outside, carries away the drillings. It is in great favor with geologists and explorers, because the core gives a complete, unmutilated section of the rocks penetrated.

3. *Driven wells.*—In sinking wells in drift, or other unconsolidated beds, simpler and cheaper devices are much in use. The most expeditious, when practicable, is the "drive well"; merely a tube, armed with a conical point, and a section of perforated pipe, forced into the ground by a maul, or by dropping a block or beam upon it, pile-driver fashion, until the perforated section reaches the porous stratum, when the water flows in and rises to the surface. This, of course, is limited to shallow wells, whose confining stratum offers no serious impediment to penetration. The bowlders of drift-beds sometimes impose obstacles, but in so simple an operation it is easy to withdraw the tube and try again.

4. *Earth augers.*—In other instances earth augers are used, not unlike the common post auger, by means of which a bore of large size is rapidly and cheaply sunk. This is, of course, subject to like interference in stony clays or very coarse gravel.

5. *Cost of wells.*—The expense of sinking a well manifestly varies greatly with the character of the strata, the depth, and the cost of power and labor in the region in which it is sunk. So far as my knowledge extends it is not customary to vary the rate for the different kinds of sedimentary rocks, limestones, sandstones, and shales. Where re-

[11] Second Geol. Surv. Penn. Oil Regions, III.

quired to penetrate granite or other crystalline rocks, an increased rate is very properly demanded. To attempt to distinguish between limestone, sandstone, and shales would lead to endless difficulty, as they not only graduate into each other, but are often intimately interleaved. The driller, familiar with the general character of the strata of the region, demands an average price, dependent on depth. While this varies, an approximate idea of the expense may be obtained by reckoning from $2 to $3 dollars per foot for the first 1,000 feet, and an increase of a half dollar per foot for each 500 feet below that down to the limits practicable for drilling. To this is to be added the cost of tubing, which will vary greatly with the situation and character of the strata.

RECORD OF DRILLINGS.

The importance of keeping a careful record of the strata encountered in the progress of drilling needs emphasis, both on account of its practical and scientific value. The record should embrace not only accurate measurements of the successive strata traversed, accompanied by careful notes on their character and a full suite of samples, but also a record of all features relating to their water-bearing nature. Some of these, that seem trivial, often have much significance when critically examined and expertly interpreted. If the diamond drill is used, the cores, of course, furnish an exceptionally excellent record in themselves, if completely and carefully preserved and placed in their natural succession, besides being an interesting exhibit of much geological interest. Since, however, these are apt to be disarranged, they should be consecutively numbered, as taken out, and, since the softer portions of the core are liable to be much broken, supplementary measurements and notes are also desirable.

From what has been previously said, the importance of knowing precisely where to locate the permanent packing is apparent. Economy dictates that it be placed as near the surface as prudent, not only to save the cost of pipe, but also the reduction in the size of the bore caused by the insertion of the pipe, and the consequent increase of friction. At the same time it is important to cut off all dangerous lateral leakage, and forestall an early decline in the flow of the well. An accurate knowledge of the strata penetrated is the only trustworthy means of doing this.

Again, when any defect in the first tubing and packing develops itself, a careful record is a valuable aid in detecting the nature and cause of the defect, and determining the means for its correction. The original driller may have thought his general observation and memory a sufficient guide for the first adjustment, but if years have passed, neither the driller nor his memory may be within available reach. The party

contracting for the sinking of a well should invariably insist upon an accurate written record, which should be preserved and transmitted with the property. The authorities of civic corporations superintending public wells should place such records on file among official documents.

When resort is had to the use of torpedoes, the precise point at which they are to be located is a matter of vital importance, and the exact depth at which the effects of explosion will presumably produce the greatest effect can only be determined by an accurate knowledge of the succession of the strata and their varying characters.

Recurring to the discussion of the testing and control of waters derived from different beds, the need of specific knowledge becomes self-evident.

It is unnecessary to enlarge upon the scientific value of such records, not only as guides in the antecedent study of proposed wells, but as direct and positive knowledge concerning the geological column, and many subsidiary phenomena.

In summation, the aid rendered in determining temporary tests, the location of permanent packing, the detection of the cause and place of defects leading to decline, the relocation of any necessary repacking, the firing of explosives, either at first or subsequently, the predetermination of success or failure in other attempts, and the light thrown on various geologic questions, combine to emphasize the importance of careful records of the drilling and the preservation of its products.

Interpretation of the drillings.—To the inexperienced the interpretation of the drillings offers some puzzles and pitfalls, though the phenomena are in reality quite simple. When the prudent driller has procured the insertion of a clause in the contract releasing him from his obligation when "granite," or the Archæan rocks, have been reached, a question for the arbitration of the geologist is apt to arise, since the other contracting party, failing of success thus far, not unnaturally desires to drive deeper. Now, the question would not usually be difficult or misleading were the drillings which are submitted merely those of the rock at the bottom of the well. But the rods or ropes and tools of the drill, by their vibration, strike the walls of the well and rattle down grains or fragments from the strata above, and these, mingling with the true drillings, often produce a curious intermixture, and if the simple fact of such a double origin is neglected, a wild interpretation will be the inevitable result. The harder the bottom rock, and the more friable the rock above, the greater the disproportion between the true and the false drillings, especially when rods are used instead of rope. When working in granite, beneath Potsdam sandstone, I have sometimes found less than 10 per cent. of the samples brought up by the sand-pump to be bottom drillings. In these cases rods instead of ropes were used. The basis for discrimination between the true and the false drillings is found in the angular forms and the fresh fractures, interpreted in the light of

previous knowledge of the strata, the rate of the drilling, the character of the stroke, and other attendant evidences. Only the direct stroke of the drill is usually competent to give chips of hard rock of any notable size having the fracture-forms peculiar to such an origin; and these are to be sought as the best indications of the constitution of the rock being wrought upon.

In the penetration of hard rock, steel flakes and splinters broken from the drill, and metallic films rubbed from it, are not uncommon features. Brought up wet, they soon rust and are liable to be interpreted as ferruginous ingredients of the rock. The inconsistency of their color with the magnetic susceptibility which the unoxidized core retains betrays their true character.

AREAS OF FAVORABLE, DOUBTFUL, AND ADVERSE PROBABILITIES.

It is the proper function of geological investigation to ascertain the stratigraphic conditions which determine success or failure. As the outcome of completed investigations, it is possible to map off the face of the country into (1) areas in which success may reasonably be anticipated, (2) areas in which the conditions are nearly balanced, and in which local and indeterminate conditions will decide success or failure, and (3) areas in which the conditions are adverse, if not altogether prohibitory. The service which such maps are competent to render in encouraging the utilization of an important resource, or in teaching caution and circumspection where uncertain results alone can be anticipated, or in forbidding useless expenditure, need not be argued. Such classification of areas has been attempted in one or more states,[12] but a general map for our vast domain is yet a hope of the future.

From the foregoing considerations it is manifest that the areas of probable success must be the relatively low tracts, that the areas of adverse probabilities are the relatively high regions, and that the doubtful belts lie between. The fallacy of an abundant supply, "if you only go deep enough," is altogether overshadowed by the singular notion, not altogether uncommon, that high lands are favorable locations for artesian fountains. The origin of this surprising illusion I am unable to fathom.

The greatest sources of indefensible expenditure are (1) the selection of a location of too great relative altitude, in defiance of the simple fundamental principle of artesian flowage, and (2) the penetration of unproductive strata, after all favorable chances have been exhausted in disregard of the fundamental laws that govern the distribution of subterranean waters.

[12] Geol. Wis., Vol. I, p. 697.

Special study.—In the face of so many possibilities of failure, the importance of a special consideration of the assemblage of conditions that surround a proposed undertaking, in a region not previously proved, or in a situation in any important respect dissimilar from those already tested, need not be pressed. The central purpose of this paper has been to call into prominence the varied qualifying conditions that solicit consideration, and, if possible, stimulate and aid those special discriminative studies which lead to an intelligent confidence of success or a prudent withholding from failure.

PRELIMINARY PAPER

ON AN

INVESTIGATION OF THE ARCHÆAN FORMATIONS

OF THE

NORTHWESTERN STATES.

BY

R. D. IRVING.

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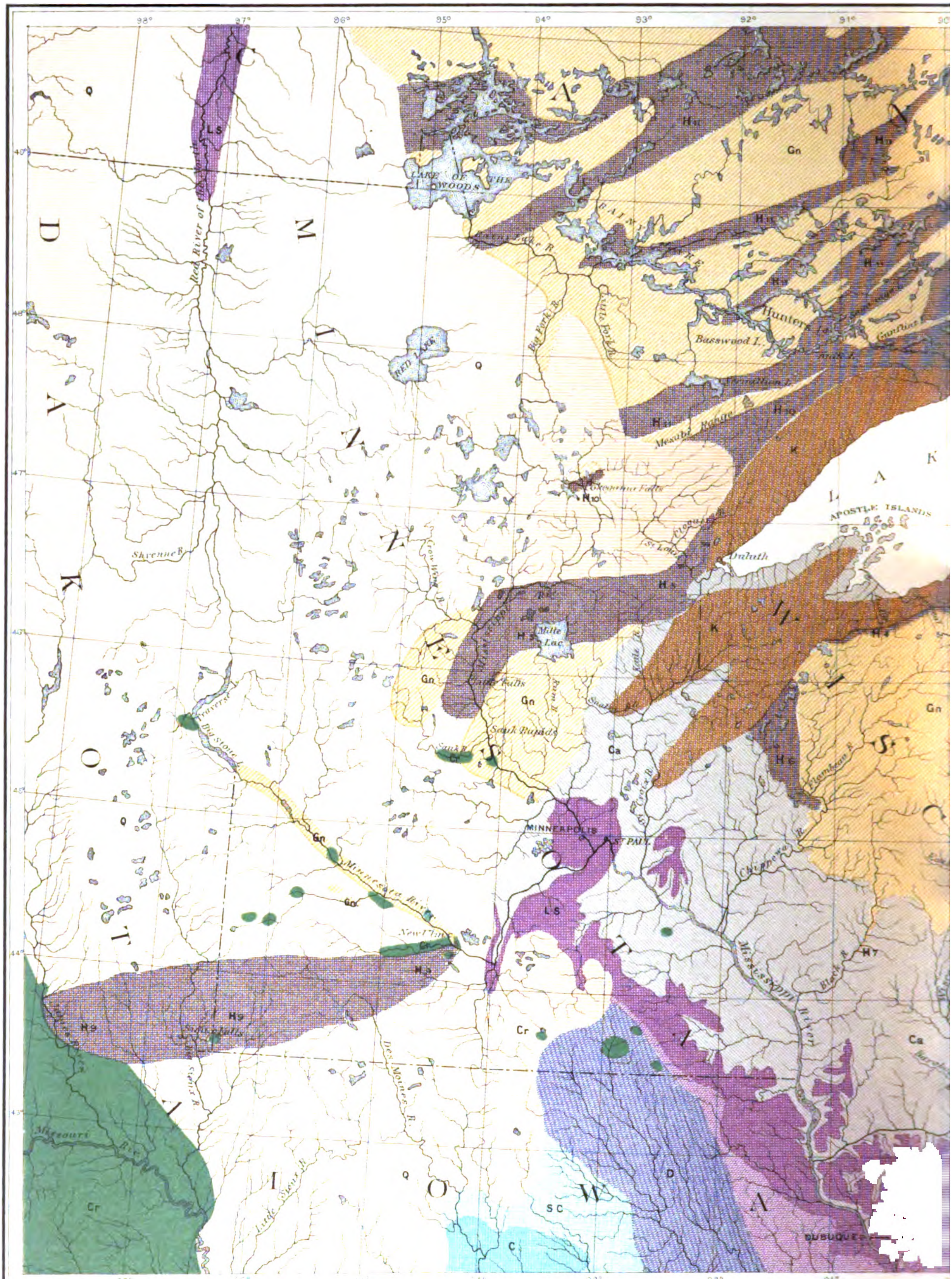
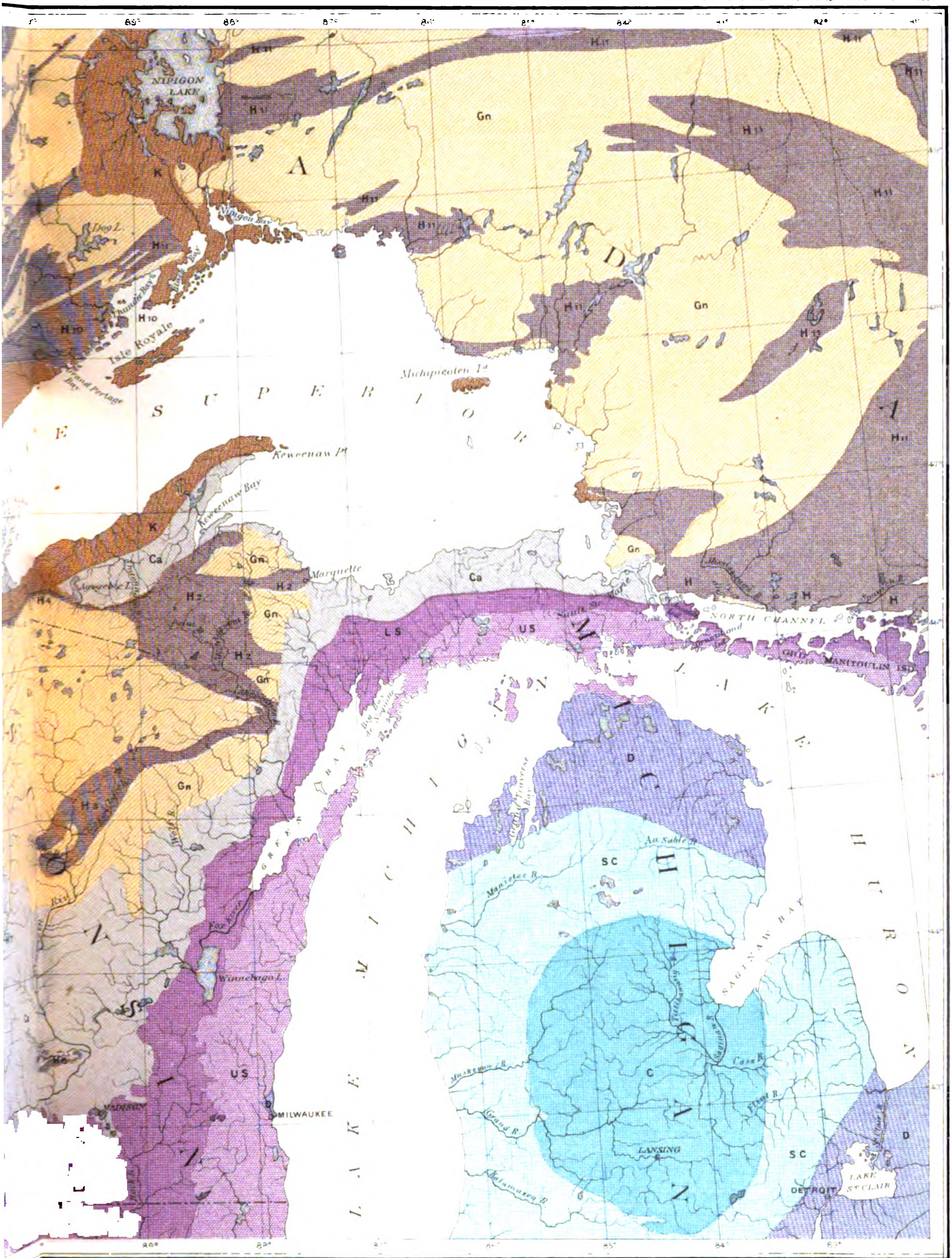
ILLUSTRATIONS.



QUATERNARY	CRETACEOUS	CARBONIFEROUS		DEVONIAN	SILURIAN		CA
(Concealing other formations)		Coal Measures	Sub Carboniferous		Upper Silurian	Lower Silurian	
Q		C	SC	D	US		

PRELIMINARY GEOLOGICAL

Compiled by R. D. Irving to accompany Rep...



Julius Bien & Co. Lith.

(CAM)BRIAN	GROUP ?	GROUP ?	GROUP ?
(Magnesian Potsdam)	Keeweenaw Series (Pre Potsdam Post Huronian)	Huronian	(Granite and Gneiss with some Schists)
Ca			Gn

FORMATIONS COLORED HURONIAN PROVISIONALLY

- H The Original Huronian
- H2 The Marquette Menominee Iron Bearing Schists
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MAP OF THE NORTHWEST.

(Progress on the Pre Cambrian Formations

PRELIMINARY PAPER ON AN INVESTIGATION OF THE ARCHÆAN FORMATIONS OF THE NORTHWESTERN STATES.

BY R. D. IRVING.

SCOPE OF THE INVESTIGATION.

The object of this paper is to present briefly an account of the work in which I am engaged upon the older formations; of the problems to be attacked and the plan of operations, with some account of the results thus far obtained.

Starting with the aid of the work done by numerous geologists on these formations during the last forty years, and with a personal acquaintance with them extending over ten years, by filling up gaps left in our knowledge, and by making use of the newer petrographical methods, in which the great advance has been made chiefly since most of the older work referred to was done, it is designed to collect the material for the preparation of a general comprehensive account of these Archæan formations for the whole Northwest. The area included in the study is very large, stretching from Lake Huron to southeastern Dakota, and the problems in correlation, structure, and genesis are numerous and difficult. The plan of operations is correspondingly comprehensive, and it is not to be expected that the results obtained thus far can be much more than fragmentary.

PRELIMINARY GEOLOGICAL MAP OF THE REGION.

The general distribution of the formations under survey, and the positions of the several subordinate districts to which I shall refer, are indicated on the accompanying preliminary geological map of the Northwest. This map I have compiled from various sources, including our own results to date. For the Paleozoic formations, the maps of Logan, for Canada; of Rominger, for Michigan; of Chamberlin, the writer, and Strong, for Wisconsin; of White, for Iowa, and of N. H. Winchell, for Minnesota, have been chiefly followed. I have departed from Winchell's mapping, however, in placing, provisionally at least, the quartzites of southern Minnesota and of the Pokegoma Falls region on the Up-

per Mississippi, as Huronian rather than Cambrian. On the various maps from which the compilation has been made the Paleozoic formations are subdivided in considerable detail. In grouping the subdivisions I have placed as Cambrian the Potsdam sandstone and the Lower Magnesian limestone, and as Lower Silurian, the St. Peter's sandstone, the Trenton limestone, and the Cincinnati group. The copper bearing or Keweenawan rocks of Lake Superior have been given a color of their own. That they are older than the Potsdam sandstone I think there can be no question, and as yet I see no reason for spreading the term Cambrian over the great break between these two formations In mapping the Keweenawan rocks I have followed my own maps as contained in the Third Annual Report of the United States Survey.

In mapping the older or Archæan formations I have preserved, provisionally, the separation between the older gneissic series, the so-called Laurentian of the Canadian geologists, and the later more distinctly stratified Archæan, all of which is provisionally grouped under the head of "Huronian." Doubtless large areas of eruptive granite of at least as late a date as the so-called Huronian have done duty heretofore as Laurentian, but it will not be possible to separate them from it until after much laborious field work. On the other hand, the term Huronian has been very irregularly used by different writers; some spreading the term over all the non-gneissic schistose rocks, whether apparently conformable with the older gneisses or not, while others have regarded the term as belonging properly only to those rocks which are more or less distinctly unconformable with the so-called Laurentian. For the present I have included under the color for Huronian all of the rocks mapped by any of the later authorities as such—separating from one another by the lettering on the face of the map (H, H_2, etc.) for convenience of reference and discussion, the various areas of so-called Huronian rocks, as to whose equivalency opinions differ.

Each one of these areas receives separate consideration below. In mapping them I have followed for Canada the latest maps of the Canadian Geological Survey, only departing from them in separating the so-called Animikie group of the Thunder Bay region from the Keweenaw series, to which it has been considered by the Canadian geologists to belong, and in including it provisionally under the color for Huronian. The Canadian maps followed differ greatly in date, some—as for instance those of the vicinity of the Lake of the Woods and of the region northeast of Lake Superior—being as recent as 1883, while others date back as far as 1863. A portion of the region north and northwest of Thunder Bay has been copied from a small-scale manuscript map furnished me by the director of the Canadian Geological Survey in 1881, and based upon the work of Bell between the years 1869 and 1879. For Michigan and Wisconsin the mapping of the State reports has been mainly followed, a few modifications from our own work having been introduced. For Minnesota none of the maps hitherto published have been followed;

but, after coloring for Quaternary a large area where the underlying rocks are probably Archæan, but are thoroughly concealed by heavy morainic or lacustrine deposits of the Quaternary, the Archæan of the remainder of the State has been compiled from our own observations, and the numerous localities of rocks given by the United States report of D. D. Owen and his assistants, and the various State reports of Minnesota by N. H. Winchell and Warren Upham.

PROBLEMS TO BE ATTACKED.

The problems to be attacked may be conveniently classified as structural, genetic, and correlative.

STRUCTURAL PROBLEMS.

Under the first of these heads comes, as of the first importance, the question of stratigraphy in each of the regions of more or less distinctly stratified rocks. In the purely granitic areas this question will not present itself, and it is very doubtful whether anything in the way of a determination of a succession of layers can be accomplished in the regions where the rock is mainly gneissic; but in each one of those regions where the rocks are distinctly stratified, in other words, in each of those areas provisionally colored on the accompanying map as Huronian, the succession of layers may be more or less satisfactorily made out. In some of these areas, as for instance the Penokee-Gogebic belt of northern Wisconsin and northwestern Michigan, the working out of a succession of layers is sufficiently simple, the only serious obstacle consisting in the heavy drift covering by which some of the softer layers are masked. On the other hand, in such areas as those of the iron regions of Marquette, Michigan, and the Menominee River in Michigan and Wisconsin, besides the obstacle of frequent heavy drift covering, an additional and more serious difficulty is met with in the complex folding to which the rock layers have been subjected. So great is this difficulty and so divergent have been the views of different writers in regard to structure in these regions that one cannot hope to do much in the way of clearing up the matter, without more accurate topographical maps than have been hitherto attainable. The satisfactory determination of the stratigraphy of these various regions is, of course, not only important in each case for the region itself, but to aid in solving the broader problems of correlation.

Of nearly equal importance with the problems in general stratigraphy in each of these areas, and in fact almost inseparable from them, are those which present themselves as to the structural relations of those rocks which are distinctly of sedimentary origin to others that are, or may be, of eruptive origin—for instance, the numerous greenstones (chiefly dia-

bases) of the various provisionally so-called Huronian areas. Do these greenstones so lie with regard to the adjoining rocks that they are always plainly of subsequent eruptive origin? Or have they been erupted cotemporaneously with the formation of the surrounding sediments? Or does the view still maintained by many, viz, that they are always but portions of the original sediments, and therefore of "metamorphic" origin, receive any support in the way of gradation into, and completely parallel interstratification with, the adjoining schists? Or can structural evidence be gathered in favor of a separation of these greenstones into the two classes of eruptive and metamorphic?

Again, very contradictory views have been held with regard to the relative positions and origin of the masses of gneiss and granite found adjoining the areas of plainly bedded schists. These granites and gneisses have been considered by different authorities as portions of the ancient basement upon which the adjacent schists were originally spread as sediments; as having been erupted during the process of the sedimentation of the adjacent schists; as erupted in great masses altogether subsequent to the formation of the schists, which they have changed into their present condition and have crowded together into crumpled troughs; and as, in part at least, forming portions of the adjoining schists, their present condition having been reached through metamorphism. It is thus evidently important to gather all the structural evidence that is possible to aid in determining which of these views is correct, or whether there are not really granites and gneisses altogether antecedent to the schists and others that were erupted during or subsequent to their formation.

It is also evidently very important to gather in any one of these schistose areas structural evidence as to the existence or absence of any breaks in the succession, such as would warrant us in separating the schists into two or more distinct groups; and in the same connection are to be mentioned the questions of structural relation to adjoining formations of undoubtedly earlier or later age. As indicated below, other broader questions in structure come in in connection with the problems in correlation; while a yet grander structural problem than any of these, and one, indeed, which can only be solved by solving first nearly all of the other problems here enumerated, is that of the Lake Superior Basin as a whole, the term basin being used here in the geological rather than the topographical sense. I have already made a first attempt elsewhere[1] to work out the structure of the middle portion of this trough, occupied by the Keweenawan rocks and the unfolded slaty rocks underlying them. Plainly, however, this is but the beginning of the subject. The various belts and areas of folded schists, as will be readily gathered by a glance at the accompanying plate, have plainly definite relations, as to structure and origin, to the trough in the Kewee-

[1] Third Annual Report U. S. Geological Survey, pp. 174-179, and Plate XVI. Also Monog. U. S. G. S., Vol. V.

nawan rocks. The folding of these schists, the production of the Keweenawan Basin, the extravasation of an enormous amount of eruptive matter during the Keweenawan and earlier periods, are all plainly the effects of one underlying cause and must be studied together.

GENETIC PROBLEMS.

Under this head come very numerous and important questions of different degrees of difficulty. We may merely mention some of them. Are the gneisses and granites hitherto classed as Laurentian altogether metamorphosed sediments or altogether the result of solidification from a molten condition? Or, have they been produced in both of these ways? If metamorphic, what was the nature of the metamorphosing process, and can any traces of the original fragmental structure be detected? Are the various schistose rocks altogether of sedimentary origin, or are they separable into two groups, one including kinds whose schistose structure has been produced by secondary changes upon eruptive masses, and another including kinds in which the parallel structure is entirely the result of sedimentation? Are the crystalline basic and acid rocks interbedded among the slates and schists altogether eruptive or are they partly recrystallized from sediments? For those rocks distinctly of sedimentary origin, what has been the nature and extent of the changes that they have undergone in reaching their present conditions? Are the wide-spread iron ores and jaspery rocks among the schists of the Northwest of eruptive, of metamorphic, or of purely chemical origin? What has been the origin of the cherty rocks which form so prominent a feature of certain of the schistose areas, notably that north of Lake Huron? How far have metasomatic processes been concerned in bringing any of these rocks to their present conditions, in imparting to rocks really of eruptive origin deceptive appearances of a sedimentary one, and to fragmental rocks equally deceptive appearances of complete original crystallization? As indicated in the previous paragraph, structural evidence must largely be made use of in the attempt to solve any of these problems, but it is in this connection especially that we must make use of microscopical methods of investigation.

PROBLEMS IN CORRELATION.

Here come not only the broader questions of correlation between the ancient rocks, which form the subject of our work, and the pre-Cambrian formations of other regions, but the much more important ones—because much more likely of solution—of correlation between the rocks of different portions of the region itself. How far is the provisional grouping of the Archæan formations into Huronian and Gneissic or Laurentian, indicated on the accompanying map, a natural one? Do the areas colored for gneiss, etc., include rocks which belong with others included within the areas colored for Huronian, and *vice versa*?

Supposing that neither one of these groups of areas covers rocks which properly belong with the other, how far are the rocks of the various so-called Huronian areas really the equivalents of the typical Huronian of the north shore of Lake Huron? If all deserve the term Huronian, to what extent were the areas, now more or less separated from one another, once continuous? In this connection evidently arise important structural problems; for instance, the case of the relation between the unfolded Animikie slates and quartzites and the folded slates which lie to the north of them, along the national boundary. The latter slates are considered by the Canadian geologists as the equivalents of the original Huronian, while to me it has seemed that the former slates are Huronian. These two formations approach each other closely in the vicinity of Knife, Gunflint, and Kingfisher Lakes on the boundary, and in this vicinity a knotty, but by no means insoluble, problem in structure has to be attacked. We have here a case of great unconformity between two sets of rocks, or the sudden passage of an unfolded into a highly crumpled series.

GENERAL PLAN OF OPERATIONS.

My plan of operations was briefly foreshadowed in my administrative report for the year ending June 30, 1883.[2] It has been, in short, (1) to obtain for myself a general personal acquaintance with all portions of the field; (2) to devote myself personally to detailed examinations of such points as have most bearing on the various problems above indicated; (3) to have all such portions of the field as have not yet been thoroughly gone over by former students, examined in detail by subordinate parties whose note-books and specimens, prepared in accordance with a uniform system, come together at the headquarters of the division for study and comparison, the chief of each subordinate party being encouraged to prepare a general account of the results of his work for separate publication as a bulletin of the Survey; and (4) to arrange our lithological studies so as far as practicable to consider together all of one class of rocks from all portions of the region.

[2] Fourth Annual Report of the U. S. Geological Survey, pp. 28–34.

VIEW OF QUARTZITE RIDGES [illegible]

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V

FIELD INVESTIGATIONS.

INVESTIGATIONS IN HURONIAN AREAS.

The various areas provisionally colored for Huronian on the accompanying map are as follows:

1. The original Huronian area of Murray and Logan on the north shore of Lake Huron between Saint Mary's and Blind Rivers (marked H on the map).
2. The Marquette and Menominee iron regions of Michigan and Wisconsin (H_2).
3. The area of the upper Wisconsin Valley (H_3).
4. The Penokee-Gogebic iron region of northern Wisconsin and northwestern Michigan (H_4).
5. The slate belt of the Saint Louis and Mississippi Rivers, Minnesota (H_5).
6. The quartzite areas of the Chippewa Valley, western Wisconsin (H_6).
7. The iron-bearing areas of the Black River Valley, western Wisconsin (H_7).
8. The Baraboo quartzite region of southern central Wisconsin (H_8).
9. The red quartzite and sandstone areas of southwestern Minnesota, southeastern Dakota, and northwestern Iowa (H_9).
10. The area occupied by the Animikie series of the Thunder Bay region, and thence southwestward to Pokegama Falls on the Mississippi (H_{10}).
11. The various belt-like areas of folded schists occurring within the great gneissic region of Canada and extending thence across the boundary into Northern Minnesota (H_{11}).

To each of these areas I devote a few words, to indicate the work we have thus far accomplished and our plan for future work in each.

THE ORIGINAL HURONIAN.

The rocks to which the name Huronian was originally given by Logan and Murray occupy an area along the north shore of Lake Huron between the Saint Mary's and Blind Rivers. This area is described in brief and mapped in some detail in the Geology of Canada (1863). Since its rocks should evidently serve as a type to which all other supposed Huronian formations must be referred, it was plainly of the first importance to obtain a thorough acquaintance with it. With this object

in view the coast line from the Sault Ste. Marie eastward to Serpent River Bay was examined in some detail during the summer of 1883 by myself and Assistant Geologists Van Hise and Merriam, with Logan's map in hand; while the country back from the coast was traversed sufficiently to enable us to see those members of the series which do not reach the coast-line. In this way we were enabled to obtain a thoroughly good acquaintance with this typical region.

The series of rocks here displayed may be briefly characterized as a great succession of quartzite layers, including a subordinate quantity of graywackes, a much smaller proportion of limestone and chert, and numerous greenstones of eruptive origin, the latter occurring both in dike and interbedded form.[3] The series is bent into gentle folds. We have now studied a large number of thin sections of the various rocks of the series, and we find the quartzites, graywackes, and slates to be little more than indurated sediments, the principal change in them having been an induration by silicious infiltration, the interstitial quartz thus produced having in large measure divided itself off into areas optically continuous with the original fragments whose outlines are usually more or less distinctly visible. More or less metasomatic alteration of the feldspathic fragments in the graywackes has been undergone, and possibly these fragments have at times received secondary

[3] I am aware that the Huronian has sometimes been spoken of as characterized mainly by other rocks than quartzites. In "Azoic Rocks," Second Geol. Surv. Penn., p. 70, Hunt speaks of Murray's first exploration of the north shore of Lake Huron as showing the existence there of "a great series of chloritic slates and conglomerates with interstratified greenstones, quartzites, and limestones." Murray's own words (Report Geol. Surv., Canada, 1847–1848, p. 109) are, "A set of regularly stratified masses, consisting of quartz rocks or altered sandstones, conglomerates, slates, and limestones, interstratified with beds of greenstone." "Under the denomination of slates are included various thinly laminated, dark-green, blackish, and reddish rocks, some of which are very chloritic, and some contain epidote." In Logan's description of the series (Geol., Canada, 1863, p. 55, and atlas to the same, Plate III) the Huronian section between the Mississaugi and Saint Mary's Rivers is made to include 10,820 feet of quartzites, 4,280 feet of "slate conglomerates," 2,000 feet of chloritic and epidotic slates and trap-like beds, and 900 feet of limestone and chert. Of the "slate conglomerates" a large proportion is quartzite, the balance being the graywackes, graywacke-slates, and graywacke-conglomerates of a subsequent part of this paper. It should be said that various intercalated greenstone layers of the series are included by Logan in these measurements. Having carefully examined the ground myself I am convinced of the general correctness of Logan's section. At least two-thirds of the series is made up of quartzite. Of the balance the graywackes of the slate conglomerate make up at least half. Of the remaining sixth one-third is limestone and chert, and the balance "chloritic and epidotic slates and trap." But these chloritic and epidotic slates, which, although so insignificant a portion of the series, have been made to serve as its most prominent characteristic, are, as I have convinced myself by examining them in their typical development just east of Thessalon Point and in the thin sections, merely eruptive diabasic greenstones in various degrees of alteration. It is possible that the occurrence of the greenish chloritic graywackes in the "slate conglomerates" has contributed to the idea that chloritic and epidotic crystalline rocks are the main characteristics of the series.

UNCONFORMITY BETWEEN LAKE SUPERIOR SANDSTONE AND HURONIAN QUARTZITE, NEAR THE MOUTH OF CARP RIVER, SOUTH SHORE OF LAKE SUPERIOR.

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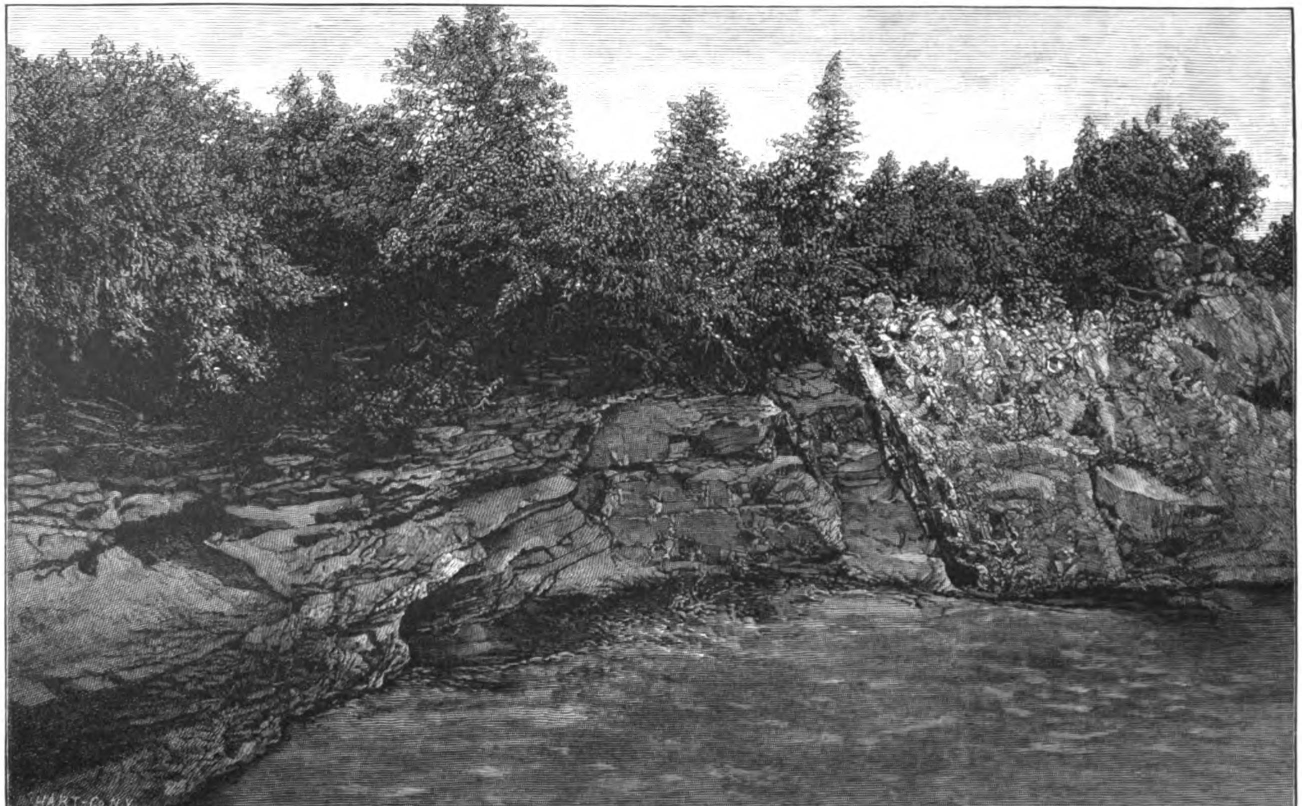
enlargements, as described below. These changes are such as are met with in entirely undisturbed and otherwise generally unaltered formations, from which they only differ here on account of the great extent to which they have been carried out. The abundant basic eruptives of the series prove to be mainly entirely augitic, in various stages of alteration, hornblende when occurring being always plainly secondary to the augite. No essential differences have as yet been detected between the interbedded and plainly intersecting greenstones, and all are closely similar to the variously altered diabases of the Marquette region. The gentleness of the foldings, the common moderate inclination of the layers and the relatively slight change which the still distinctly fragmental rocks have undergone are striking features, and more suggestive of the appearance of some of the fossiliferous formations than of the crystalline schists. It should be said, in this connection, that nowhere is the series so altered as to allow of the idea that fossils have been destroyed by metamorphism. Fossils are constantly found in rocks no more altered than these, and their non-occurrence here must be because of their original absence.

That no misunderstanding may arise, I repeat here that these statements apply to that series of rocks lying along the north shore of Lake Huron between the Saint Mary's and Blind Rivers, as mapped by Logan in the atlas to the geology of Canada (1863), Plate III, and to no others.

THE MARQUETTE AND MENOMINEE IRON-BEARING SERIES.

The rocks of this series are highly folded, and their structure is often very difficult to work out. Moreover, the metasomatic changes which the crystalline members of the series have undergone have often been extreme; added to which difficulties are frequent interruptions by drift covering.

Although studied more minutely and by more different authorities than any other portion of the region the divergencies of view as to structure and genesis in this region, even among the later writers, have been very great. In attempting to unravel the difficulties here presented, so as to set some at least of these disputed questions beyond controversy, the need of very careful topographical mapping becomes apparent. My plan, therefore, with this region has been to obtain a thorough acquaintance with all its prominent localities, examining them with the various former descriptions in hand, and to defer any attempt at minute structural work until better maps than are now available could be prepared. During the past year we have visited all of the prominent points of the region, and have made some progress in the microscopic examination of the numerous specimens collected. Although there is yet so much to be accomplished in this region, I have been led already to some conclusions with regard to it that seem unlikely to be disturbed.



UNCONFORMITY BETWEEN LAKE SUPERIOR SANDSTONE AND HURONIAN QUARTZITE, NEAR THE MOUTH OF CARP RIVER, SOUTH SHORE OF LAKE SUPERIOR.

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In the first place, after having obtained a thorough acquaintance with the rocks of this region, and those of the type region of Lake Huron, no doubt remains in my mind as to the correctness of the position of those who have heretofore regarded the two series as equivalent. I came away from the Marquette region, indeed, with a good deal of doubt as to whether some of the greenish schists included by Brooks, Rominger, and others within the lower portion of the iron-bearing series, might not really belong with the older gneissic formation. Excluding these schists, the remainder of the series has a distinctly Huronian aspect. Like the latter it may be described as in the main a fragmental slate and quartzite series, including a large proportion of basic eruptives. As is already well known, these eruptives are chiefly diabasic. That all of them were probably originally so has already been maintained by myself, as well as by others. Besides the quartzites, magnetitic schists, chert-schists, iron ores, limestones, dolomites, clay-slates, mica-slates, and greenstones, which make up the bulk of the Marquette series, a number of other less abundant kinds have been described as occurring. It is among these kinds that the lithological differences between the rocks of this region and those of the typical Huronian area of Lake Huron are found. I have elsewhere[4] suggested that these differences are probably more seeming than real, and the result from subsequent study in the field and laboratory has been to confirm the correctness of this suggestion.

A considerable proportion of these unusual kinds are plainly but the results of metasomatic changes upon the ordinary basic eruptives of the series, and in the list of rocks so produced come, I think, in all probability, a number of the so-called hornblende-schists and actinolite schists, kinds which, if, as ordinarily supposed, of sedimentary origin, must be believed to have undergone a far more extreme degree of metamorphism than the bulk of the series. Many excellent authorities, having observed the gradation of these schists into the adjoining crystalline greenstones, accepting the schistose structure as a proof of sedimentary origin, have been led to maintain a sedimentary or metamorphic origin for the latter rocks also; while others, realizing the strength of the evidence in favor of the eruptive origin of the greenstones, have felt compelled to deny a graduation between them and the associated schists. To me, however, while I do not doubt that in some cases such a graduation has been assumed to exist where it does not, it certainly seems to do so in many other cases, as, for instance, that of the exposures at Big and Little Quinnesec Falls, on the Menomonee River, and to lead inevitably to the conclusion that both schists and greenstones are of eruptive origin, the former representing merely an extreme degree of a metasomatic change, which in some measure has influenced all of the greenstones.

It is well known that Brooks has worked out in some detail a scheme

[4] Monog. U. S. Geol. Surv., Vol. V, pp. 393–395.

of stratigraphy for this difficult region.[5] More recently Brooks's scheme of stratigraphy has been disputed by Rominger, who maintains an arrangement in the main quite different from that of Brooks.[6] But it does not seem to me that any very conclusive opinion as to this matter can be reached without, in the first place, a thoroughly good map or series of maps to work with, and in the second the extension of a detailed microscopic investigation hand in hand with the field work, over the whole region, for the purpose of correlating the various exposures. In one respect, indeed, I feel quite confident that Brooks' scheme must be modified. I refer to his various greenstone layers (XI, IX, VII, and below V),[7] including certain hornblende rocks and hornblende schists, and some of the chloritic schists of the series. That these rocks represent often basic eruptives in various stages of alteration there can, I think, be little doubt; in which opinion I follow, in a measure at least, Foster and Whitney, Wadsworth, Rominger, and others. That some of these eruptive greenstones represent flows contemporaneous with the series, and hence, in a certain sense, forming regular layers in it, is evident; but others of them are plainly intrusive or of subsequent origin, while even those that are interfolded with the series are more probably detached lenticular masses than portions of great members of the series coextensive with the region.

Ever since the discovery of this interesting region there has been much discussion as to the origin of its peculiar beds of iron ore, which, in many respects, especially in the peculiar lamination with reddish jasper that they present, are different from other iron ores of the world. In conformity with views then held with regard to the origin of many of the great specular and magnetic ore-bodies of other parts of the world, Foster and Whitney, the earliest writers of importance on this region, described these ores also as of eruptive origin. Since then a long list of writers have maintained the sedimentary origin of these ores, their present condition being taken generally to be due to a metamorphism from a former condition somewhat nearly like that of the various stratified iron ores of the unaltered Paleozoic rocks, such as the Clinton ore, the various stratified ores of the Coal Measures, and the bog-iron ores of the present period. Quite recently Wadsworth has revived the theory of the eruptive origin of the ores and associated jaspery schists, and has maintained their general similarity to the acid or rhyolitic eruptions of the later geological periods,[8] to whose frequent fluctuation structures he has likened the bandings of the jaspery

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[5] Geological Survey of Michigan, Vol. I, 1873, Part I, p. 83, and accompanying atlas plates; also Geology of Wisconsin, Vol. III, 1880, Part vii, Chap. I; and Table 3, opp. p. 450.

[6] Geological Survey of Michigan, Vol. IV (1881).

[7] Geological Survey of Michigan, Vol. I, Part I, p. 83.

[8] Bull. Mus. Com. Zool., whole series, Vol. VII; Geol. series, Vol. I, No. 1, pp. 28-36.

[illegible] of the jaspery rocks, as compared with any [illegible] ted, but neither this fact nor the sing[illegible] with free oxides of iron is accounted for. [illegible] in a general review of the whole subject of [illegible], while maintaining a sedimentary origin for [illegible] Lake Superior region, has advanced the view [illegible] rather in the nature of mechanical than of [illegible] the iron oxides having been washed into a frag[illegible] existing rocks, and intermingled with other sand [illegible]. It is to be noticed that on any theory of [illegible] the original sedimentary deposition of these ores, [illegible] ated and later crystalline condition is taken as the re[illegible] cess of metamorphism. During our examination of this [illegible] tion was given to the iron ores in both the Marquette [illegible] districts, with direct reference to this question of [illegible]. My studies in this connection are as yet incomplete, and I [illegible] therefore, to advance any general theory. But several [illegible] with regard to these ores which have impressed themselves upon [illegible] attention may be mentioned. In the first place, I may say that I [illegible] unable to accept any of the jaspery ores as of eruptive origin.[illegible] From the most highly contorted and confused forms we have every [illegible] tion to forms in which the sedimentary lamination seems so distinct as to render irresistible the conclusion that all are of one origin. It is unfortunate, indeed, that the ores of the Marquette district were the first studied in the Lake Superior region, for here they present their most confused and difficult appearances. Jaspery and quartzitic ores, which must, I think, be admitted by all to have had the same genesis with those of the Marquette region occur in the Penokee-Gogebic belt, and again in the Animikie formation of the national boundary, in a relatively undisturbed position and under such circumstances that their original sedimentary deposition seems to be placed beyond doubt. What has been

[illegible] Genesis of the Crystalline Iron Ores, Engineering and Mining Journal, [illegible] 2, 1884.

[illegible] That iron ore of eruptive origin actually does occur in masses of some little size is sufficiently evident from certain occurrences in the [illegible] region of northeast Minnesota. The frequent occurrence of titaniferous magnetite as a constituent in the eruptive basic rocks is well known, and in Minnesota, in the region above referred to, the titaniferous magnetite of certain gabbros is, in places, aggregated into considerable bodies, as for instance, on the north shore of Iron Lake, T. 65, R. 2 and 3 W., where there is a series of extraordinary aggregations of titaniferous magnetite, occurring directly in one of the great gabbro layers of the region and grading into it, the ingredients of the gabbro occurring more or less [illegible] the iron-ore masses, whilst the iron oxide similarly is scattered through and through the surrounding gabbro. The occurrence of these ore masses has been described somewhat fully by N. H. Winchell ([illegible] Annual Report Geological Survey Minnesota, pp. 8[illegible]). Some of these masses are a number of feet in thickness and [illegible] to form a more or less continuous belt some hundreds of feet in length. But they have nothing whatever in common with the jaspery ores of the Marquette region.

UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND HURONIAN IRON ORE, CYCLOPS MINE, NORWAY, MICHIGAN.

ores. The extreme acidity of the jaspery rocks, as compared with any other known eruptives, is admitted, but neither this fact nor the singular occurrence of free silica with free oxides of iron is accounted for. More recently still, Julien, in a general review of the whole subject of the origin of iron ores[9], while maintaining a sedimentary origin for the jaspery ores of the Lake Superior region, has advanced the view that they were originally rather in the nature of mechanical than of chemical sediments, the iron oxides having been washed into a fragmental form from pre-existing rocks, and intermingled with other similarly derived detritus. It is to be noticed that on any theory hitherto advanced which accepts the original sedimentary deposition of these ores, their present indurated and often crystalline condition is taken as the result of some process of metamorphism. During our examination of this region much attention was given to the iron ores in both the Marquette and the Menominee districts, with direct reference to this question of their origin. My studies in this connection are as yet incomplete, and I feel unwilling, therefore, to advance any general theory. But several points with regard to these ores which have impressed themselves upon our attention may may be mentioned. In the first place, I may say that I am quite unable to accept any of the jaspery ores as of eruptive origin.[10] From the most highly contorted and confused forms we have every gradation to forms in which the sedimentary lamination seems so distinct as to render irresistible the conclusion that all are of one origin. It is unfortunate, indeed, that the ores of the Marquette district were the first studied in the Lake Superior region, for here they present their most confused and difficult appearances. Jaspery and quartzitic ores, which must, I think, be admitted by all to have had the same genesis with those of the Marquette region, occur in the Penokee-Gogebic belt, and again in the Animikie formation of the national boundary, in a relatively undisturbed position and under such circumstances that their original sedimentary deposition seems to be placed beyond doubt. What has been

[9]Genesis of the Crystalline Iron Ores, Engineering and Mining Journal, Feb. 2, 1884.

[10]That iron ore of eruptive origin actually does occur in masses of some little size is sufficiently evident from certain occurrences in the Animikie region of northeast Minnesota. The frequent occurrence of titaniferous magnetite as a constituent in the eruptive basic rocks is well known, and in Minnesota, in the region above referred to, the titaniferous magnetite of certain gabbros is, in places, aggregated into considerable bodies, as, for instance, on the north shore of Iron Lake, T. 65, R's 2 and 3 W., where there is a series of extraordinary aggregations of titaniferous magnetite, occurring directly in one of the great gabbro layers of the region and grading into it, the ingredients of the gabbro occurring more or less plentifully through the iron-ore masses, whilst the iron oxide similarly is scattered through and through the surrounding gabbro The occurrence of these ore masses has been described somewhat fully by N. H. Winchell (Tenth Annual Report Geological Survey Minnesota, pp. 80–83). Some of these masses are a number of feet in thickness, and seem to form a more or less continuous belt some hundreds of feet in length, but they have nothing whatever in common with the jaspery ores of the Marquette region.

UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND HURONIAN IRON ORE, CYCLOPS MINE, NORWAY, MICHIGAN.

[illegible] as compared [illegible] [illegible] [illegible] of the [illegible] with [illegible] of [illegible] accounted [illegible] review of the whole [illegible] a sedimentary origin [illegible] has advanced the view that they were [illegible] either in the [illegible] of [illegible] [illegible] having been [illegible] rocks, and [illegible] with [illegible] [illegible] It is to be [illegible] that [illegible] theory [illegible] [illegible] condition is [illegible] [illegible] During our examination of this [illegible] given to the [illegible] in both the Marquette [illegible] refer [illegible] to this [illegible] [illegible] studies in this connection are as yet [illegible] therefore to advance any general theory [illegible] with regard to these ores which have impressed themselves [illegible] may now be mentioned. In the first place, I may say that I [illegible] any of the jaspery ores as of eruptive origin. [illegible] the most highly contorted and confused forms we have every [illegible] forms in which the sedimentary lamination seems so distinct as to render irresistible the conclusion that all are of one origin. It is [illegible] indeed, that the ores of the Marquette district were the [illegible] the Lake Superior region, for here they present their most [illegible] appearances. Jaspery and quartzitic ores, which [illegible] I think, [illegible] have had the same genesis with those [illegible] Penokee-Gogebic [illegible] the Animikie formation of the national boundary, in a relatively [illegible] position and under such circumstances that their original sedimentary deposition seems to be placed beyond doubt. What has been

[illegible] of [illegible] Iron Ores, Engineering and Mining Journal [illegible] 1884.

[illegible] of eruptive origin [illegible] does occur in masses of some [illegible] size is [illegible] from certain occurrences in the [illegible] of north[illegible] frequent occurrence of titaniferous magnetite as [illegible] in the eruptive basic rocks is well known, and in Minnesota, in the region above referred to, the titaniferous magnetite of certain [illegible] is, in places, [illegible] [illegible] north shore of Iron Lake, T. [illegible] R. 2 [illegible] W., where there is a series of extraordinary aggregations of [illegible] in one of the great gabbro layers of the region [illegible] [illegible] of the [illegible] more or less [illegible] ore [illegible] the iron oxide similarly is scattered through the [illegible] [illegible] these ore masses [illegible] N. H. W[illegible] American [illegible] sota [illegible] these masses are a number of feet in [illegible] to form a more or less continuous [illegible] nothing whatever in common with the jaspery ores of the Marquette region.

UNCONFORMITY BETWEEN POTSDAM SANDSTONE AND HURONIAN IRON ORE, CYCLOPS MINE, NORWAY, MICHIGAN.

the origin of the iron oxide of any of these ores, whether fragmental or chemical, or both, I do not undertake now to discuss, but that much of the quartzitic material mingled with them, particularly in the Penokee belt, has had the same fragmental origin with the associated quartzites, I have convinced myself from study in the field and from study of the thin sections. Besides this fragmental silicious material, however, and occurring frequently intermingled with it, and again at times almost or entirely excluding it, is a chalcedonic or amorphous silica. Much of the jasper of the Marquette ores seems to be made up of purely crystalline quartz, but much of it also is chalcedonic or amorphous, and this chalcedonic form appears to be particularly abundant in association with the ores of the Menominee region, where many of the great belts of ferruginous rock seem to be mainly composed of it. A similar material is abundantly present in the magnetitic schists of the Penokee and Animikie series and Vermillion Lake rocks. This, we think, is a fact which has not yet received due attention in discussions on the origin of these ores. So far as our study has extended it has seemed evident to us that this chalcedonic silica is of original formation, or at least that it existed in its present condition prior to the formation of much of the series. Wadsworth has drawn attention to a very interesting occurrence at numbers of points in the Marquette region, and has made use of it to sustain his theory of the eruptive origin of the jaspery ores. I refer to the occurrence in the quartzites overlying the ores, at several of the Marquette mines, of abundant rounded fragments derived from the ore below. A very much more striking occurrence of this kind is met with in the Vermillion Lake district of Minnesota, where the fragments included in the conglomerate overlying the iron belt are often several feet in length, and angular. That these fragments prove the existence of the jaspery and chalcedonic material in its present condition before the formation of the quartzite is sufficiently evident. That this material has had an origin—ill understood, to be sure—similar to that of many of the so-called cherts of this same formation, as, for instance, on the north shore of Lake Huron, and of the later Paleozoic formations, seems to me not improbable. It is a matter to which we expect to devote much attention during the coming year in the field and laboratory.

The maps by Brooks in the geological reports of Michigan have left indefinite the western boundaries of the Marquette and Menominee Huronian. Whether there is actually an overground connection with the iron-bearing formation of the Gogebic region, as I have represented provisionally on the accompanying maps, is yet an open question. Iron explorers have already carried the Marquette Huronian over much of the area left uncolored on Brooks's map, and it is our intention to investigate this region at an early day. In this connection should be mentioned also the matter of the western extension of the Menominee Huronian in Wisconsin. The Menominee area is believed to connect di-

rectly with that of the upper Wisconsin Valley, and is so mapped upon the final map of Wisconsin by Chamberlin, but the exact position of this extension is in some doubt. During the past season Assistant Geologist W. W. Daniells made some examinations in the neighborhood of Pelican Lake and River, and along the Milwaukee and Northern Railway, where there are a number of new artificial exposures which will enable us to map the connection more closely.

THE SCHISTS AND QUARTZITES OF THE UPPER WISCONSIN VALLEY.

In the fourth volume of the Geology of Wisconsin (1880) there is published, by the writer and Prof. C. R. Van Hise, an account, including microscopic descriptions, of the crystalline rocks of the Wisconsin Valley, from their first appearance from beneath the Potsdam sandstone northward to Grandfather Bull Falls. In this account it is shown that these crystalline rocks are in the main gneisses, among which are some mica-gneisses, but which are in large measure augitic hornblende-gneisses and even augite-gneisses. Interlaminated with and plainly subsidiary to these gneisses, which are always strongly schistose, are bands of mica-schist, hornblende-schist, and augite-schist, while areas of granite and quartziferous porphyry, which are taken to be eruptive, as also belts of various basic eruptives, here and there occur. Included within this gneissic area, in the vicinity of Wausau, Marathon County, is a belt of country in which occur a number of detached exposures of cherty greywacke-slate, mica-slate, and quartzite, which contrast so strongly with the adjacent gneisses, and are at the same time so closely allied to rocks met with in the Menominee and original Huronian, that their reference to the Huronian seems necessary. The correctness of this reference is still further strengthened by the occurrence of these exposures in the right position to be continuous with the tongue indicated on the accompanying map as extending southwestward from the Menominee region. The structural relations of these various exposures, the exact positions of the western termination of the formation, and of its connection with the tongue just referred to, were left in doubt in the Wisconsin volume. With the object of obtaining additional evidence upon these points, Prof. W. W. Daniells, during the season of 1883, made a series of explorations in the valleys of the Eau Pleine and Pelican Rivers, and along the line of the Milwaukee and Northern Railway. His explorations on the Eau Pleine resulted in the location of a number of hitherto unexamined ledges, which seem to prove that the slaty formation does not extend beyond that stream.

THE PENOKEE-GOGEBIC IRON BELT.

Extending from the vicinity of Lake Numakagon, in Wisconsin, north of east to Lake Gogebic, in Michigan, a distance of sixty miles, is a strongly marked and continuous belt of slaty and quartzitic rocks, carrying, in one portion of the series, large quantities of the magnetic and

specular oxides of iron. Unlike the iron-bearing rocks of the Marquette and Menominee districts, the structure in this region is always simple, and the dip, except in an occasional slight overturn, is always in one direction; that is, to the northward. In the vicinity of Bad River the total thickness of the series, from the chloritic gneisses on the south to the great Keweenawan gabbros on the north, is some 13,000 feet, but farther east and west the thickness appears to to be less than this. I have elsewhere argued[11] in favor of an equivalence of this slaty series with that of the Marquette region, and with the type Huronian of the north shore of Lake Huron. Having now made a thorough review of both of the latter regions, I am only the more convinced of the correctness of the position. Building upon Brooks's scheme of stratigraphy for the Marquette region, and upon my own knowledge of the Penokee series, I argued in 1880, not only for the general equivalence of the two series, but also for a stratigraphical similarity, great enough to indicate the continuity of the two formations.[12] Of the general correctness of the scheme of stratigraphical equivalency then presented, I have also been able to satisfy myself by my later studies. I have already indicated my belief that Brooks's scheme for the Marquette region will require some modification, and of course the scheme of stratigraphical equivalency between the two series will need to be correspondingly modified. But these modifications will be of minor importance, and will serve only to make the case clearer.

The maps and descriptions of the Wisconsin Survey, illustrative of the Penokee region, give such full details with regard to it as far east as the Michigan line that little if any more work will be needed west of that line. With regard to that portion of the belt which lies farther east, however, between the Montreal River and Lake Gogebic, the only information obtainable is what may be derived from the few scattering geological notes upon the township plats of the General Land Office, and from the brief account of a hasty reconnaissance made by Pumpelly and Brooks in 1872.[13]

From these sources enough may be gathered to make it evident that the Penokee belt continues through this distance in full force, but the structural features and exact position remain quite unknown. Moreover, a number of extensive explorations for iron ore made here within the last few years have proved the great value of the iron deposits of the region at a number of points. So important, therefore, is this district to our work, from both a geological and an economic point of view, that arrangements have been made to have it examined in detail by a party

[11] Geology of Wisconsin, Vol. III, pp. 66, 163; also, Annual Report United States Geological Survey, p. 165; also, Monographs United States Geological Survey, Vol. V, p. 391.

[12] Geology of Wisconsin, III, pp. 163–166.

[13] Am. Jour. Sci., June, 1872. Also, Geol. Surv. Mich., 1873, Vol. I, pp. 183–186.

under Assistant Geologist Van Hise during the season just opened. Professor Van Hise will have in this examination the great advantage of a thorough familiarity with the Marquette and Menominee iron districts, and with the type Huronian of the north shore of Lake Huron, as well as with the petrography of the rocks he is likely to encounter.

Eastward from Lake Gogebic I have indicated on the accompanying map an almost continuous overground connection with the Huronian of the Marquette region. That a connection actually exists here I think there can be no doubt, but whether it is more thoroughly concealed by the overlap of the Eastern Sandstone than is indicated on the map, remains as yet a question to which we hope to find an answer during the coming season.

It is particularly desirable, for another reason, that we should gather in all obtainable facts as to the Penokee-Gogebic belt and its eastward and westward connections. I refer to the very interesting relation of this series to the great Lake Superior trough, underneath which it appears to pass continuously, to reappear on the northern side of the Lake in the shape of the so-called Animikie series. This relation is one I have already attempted elsewhere to discuss.[14]

THE SLATE BELT OF THE SAINT LOUIS AND MISSISSIPPI RIVERS, MINNESOTA.

Along the Saint Louis River in Minnesota, for some miles above and below the crossing of the Northern Pacific Railway, is exposed a great series of cleaved slates, in which the lamination due to sedimentary deposition may usually be most beautifully seen. Intersecting these slates are great dikes of gabbro. The thickness exposed is evidently very great, although the appearance of thickness is exaggerated by folding.[15] I have already argued elsewhere[16] in favor of the reference of these slates to the Huronian, and of their equivalence with the uncleaved slates of the Animikie series of the National Boundary line, the latter opinion being also held by Hunt,[17] and by N. H. Winchell,[18] Having, in the mean time, re-examined the Animikie series throughout its region of typical development, as also the type Huronian of Lake Huron, I feel no disposition to depart from these opinions. It is to be observed, however, that the slates of the Saint Louis are separated

[14] Third Annual Report U. S. Geological Survey, pp. 174–179 and Plates XVI and XVII. Also, Monographs U. S. Geological Survey, V, pp. 410–418.

[15] Folds have hitherto only been suspected in these slates, but a recent careful re-examination served to make them very plain to me. They may be particularly well seen near the wagon-bridge at Thompson, Minn., where three synclinals and three anticlinals may be traced out within a few hundred feet across the strike, the nearly vertical slaty cleavage remaining constant throughout.

[16] Geol. Wis., III, p. 18 (1880). Third Annual Report U. S. Geol. Surv. (1883), p. 102. See, also, E. T. Sweet, Geol. Wis., III, p. 384.

[17] Transactions of the Royal Society of Canada.

[18] Eleventh Annual Report Geol. Surv. Minn. (1882), p. 169. Tenth Annual Report Geol. Surv. Minn. (1881), p. 95.

from the nearest flat-lying Animikie rocks, in the Mesabi Range, south of Vermillion Lake, by a gap of 70 miles, in which the drift accumulations are so great as to obscure the underlying rocks, so far as we yet know; so that there is not much hope that we shall be able to get at anything more than a theoretical structural relation between the two sets of rocks.

At the time of the opening of our work no information was at hand with regard to the slates of this belt except in their development along the Saint Louis. Mr. Merriam, therefore, during the fall of 1882, made a detailed examination of the region between the Saint Louis and Kettle Rivers, during which he carried the slates to a distance of some 33 miles westward to the main course of the latter stream. He also made examinations in the vicinity of Mille Lacs Lake and along Rum River, and again along the Mississippi River from Brainerd to Elk River, the result of which was to show the identity and almost certain continuity of the slates of the Mississippi River, in the vicinity of Little Falls, with those of the Saint Louis. The examinations of Professor C. W. Hall, in the season of 1883, to the west of the Mississippi River, mentioned again below, have enabled us to map, approximately at least, the limit of the slates in that direction. Quite recently (June, 1884) I have received the Eleventh Annual Report of the Minnesota Survey, in which is given, by Mr. Warren Upham, a very full account of all of the exposures of central Minnesota, both east and west of the Mississippi River. With the aid that these will give us it will not be necessary to devote any more time in the field to this belt, beyond what study I may need to give personally to one or two important localities. The specimens collected by Mr. Merriam in his explorations along this belt have all been studied microscopically by Professor Van Hise. They include, among the slates, fine-grained graywacke-slates, clay-slates, sericitic quartz-slates, true quartzites, mica-slates (often hornblendic), staurolitic mica-slates (often garnetiferous), and hornblende-schists, and among the eruptives, diabases, gabbros, and diorites, the latter presumably altered forms of diabase or gabbro. Besides these microscopic results there are also available those published by Streng in 1877.[19]

THE QUARTZITES OF CHIPPEWA AND BARRON COUNTIES, WISCONSIN.

In the fourth volume of the Geology of Wisconsin,[20] Chamberlin has described a series of detached quartzite ridges, scattered over an area some 40 miles in length and 12 in breadth, on the west side of the Chippewa Valley, in western Wisconsin. He shows the similarity of the quartzites to those of the Baraboo region of southern central Wisconsin, and of southwestern Minnesota and southeastern Dakota, and their probable identity with them.

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[19] Ueber die krystallinischen Gesteie von Minnesota in Nordamerika. Neues Jahrbuch für Mineralogie, &c., 1877, pp. 31, 131, 225.

[20] Part V, p. 573–581, Atlas Plate I.

The quartzites of these areas are red, from arenaceous to highly vitreous, and carry seams of a clayey material identical with the well-known catlinite or pipestone of southwestern Minnesota. These quartzites are for the most part considerably inclined, dipping in various directions, and are apparently bent into a series of anticlinals and synclinals. Unfortunately the drift-covering between the areas is so extensive and the whole region is so heavily covered with forest, that it must prove very difficult to work out any detailed structure, and I do not expect to find it profitable to do anything here beyond making a general personal reconnaissance to enable me to make an intelligent comparison between this and other similar regions.

One point of particular interest attaching to this quartzite series is its general structural relation to the Lake Superior synclinal and to the quartzite of the Penokee Range in Wisconsin, as also to the similar red quartzites of southwestern Minnesota.

THE FERRUGINOUS SCHISTS OF THE BLACK RIVER VALLEY, WISCONSIN.

In the second volume of the Geology of Wisconsin,[21] I have described in some little detail a number of small areas of a peculiar ferruginous schist, associated with more or less of a mica-slate and of other slates, which rise through the overlying Potsdam sandstone of the Black River Valley of western Wisconsin. Both to the southwest and to the northeast of the northwestwardly trending belt in which these exposures occur, granite and gneiss are found. It is difficult to tell just how great a thickness exists here, but in one section on Black River I made out, in 1873, as much as 5,000 feet.[22]

That these ferruginous schists are geologically equivalent to the iron-bearing formations of the Penokee, Menomonee, and Marquette regions is inferred from lithological characteristics. Since the work done in this region by the Wisconsin survey in 1873, no further investigations in it have been made.

THE BARABOO QUARTZITE SERIES.

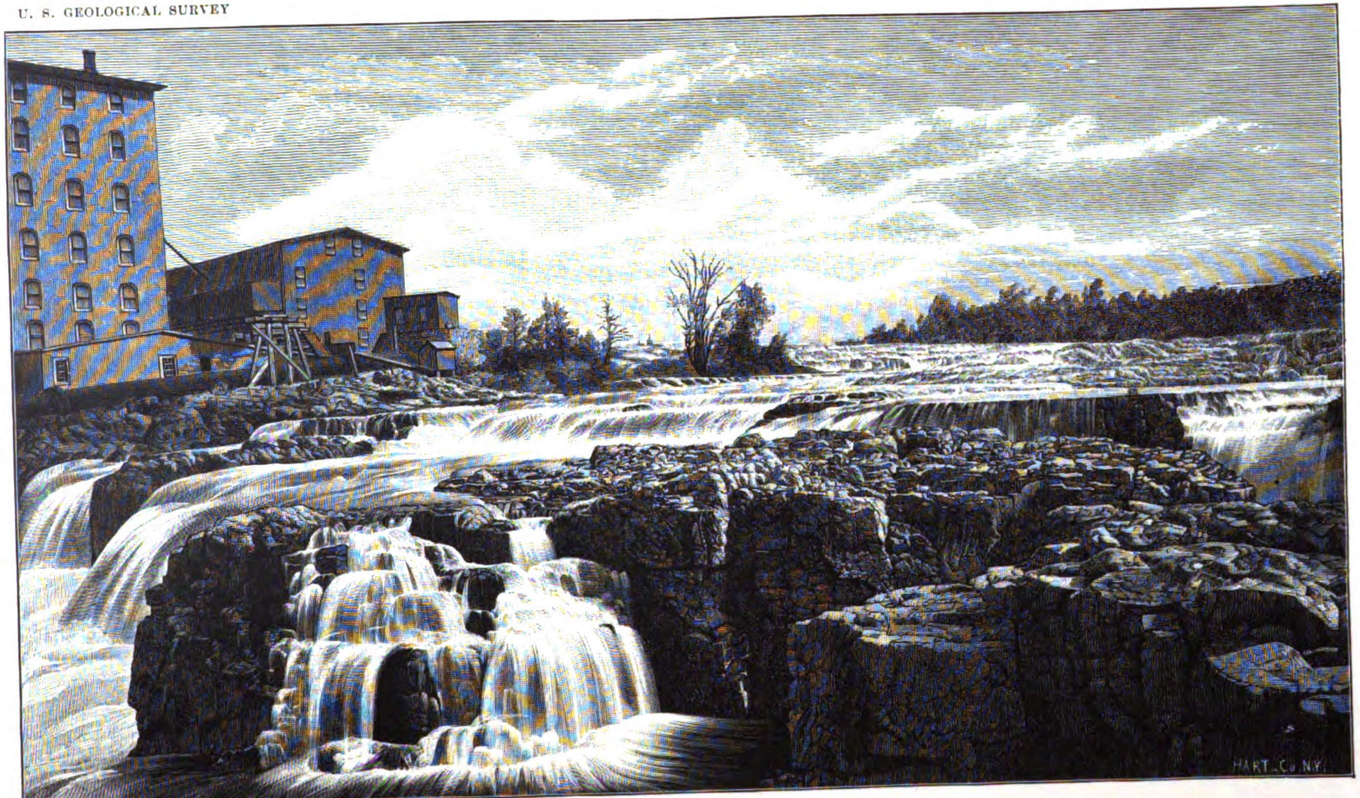
This great quartzite series, measuring many thousands of feet in thickness, composes the bold group of ridges around which the Wisconsin River makes its great eastern bend, in Sauk and Columbia Counties, Wisconsin. I have already described these rocks and mapped their distribution in considerable detail.[23]

Accompanying the predominant quartzites of this region is a great thickness of felsitic porphyry, besides which there occur also, subordinately, certain clayey schists or slates. The several ridges of the Baraboo region inclose a sort of amphitheater, through which the Baraboo River flows from west to east, breaking its way twice through the north-

[21] Pages 493–499 and Plates XVII and XVIII.

[22] Geology of Wisconsin, Vol. II, pp. 493–497.

[23] Geology of Wisconsin, Vol II, pp. 504, 519, Plates XVIII, XIX, XX, XXII, XXIII, and Atlas Plate XIV.



QUARTZITE OF SIOUX FALLS, DAKOTA—LOOKING SOUTHEAST.
(The dip is away from the observer.)

[illegible] region [illegible] sections [illegible] stone [illegible] of [illegible] the contact between the quartzite and the [illegible] is [illegible] to be seen [illegible] of Wisconsin [illegible] weathering down [illegible] and the Potsdam sandstone was [illegible] time referred to the Huronian of Canada [illegible] the latter formation seems to have [illegible] restricted [illegible] reference.

[illegible] the Baraboo ridges [illegible] through the horizontal sandstone of the [illegible] porphyries and others of granite. The [illegible] of [illegible] that associated with the quartzites [illegible] their geographical distribution [illegible] to the north [illegible] under the [illegible] sandstone [illegible] porphyry, while the [illegible] quartzite [illegible] quartzites and schists [illegible] east [illegible] porphyry [illegible] a similar northeastward extension of the [illegible] connection with the Baraboo series, and as evidence [illegible] should be mentioned the detached areas of quartzite [illegible] and western Jefferson counties, in Wisconsin [illegible] thoroughly described and mapped in the Wisconsin [illegible] material [illegible] them in my hands is so plentiful [illegible] will require any further consideration [illegible] examined in connection with [illegible] of quartzite from [illegible] region, and [illegible] expect to study [illegible] also a number of sections of [illegible]

THE QUARTZITE SERIES OF SOUTHERN MINNESOTA AND SOUTHEASTERN DAKOTA

West of the [illegible], in Minnesota, the older formations are for the most part concealed by the overlying Quaternary accumulations which include both morainic glacial depositions, and [illegible]

[illegible] Geol. Wis., Vol. II, Plate X [illegible]

[illegible] Geol. of Wis., Vol. II, pp. 2[illegible] 266.

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ern set of ridges, both on entering and on leaving the valley. This central valley, as also the outside country, is everywhere underlaid by the friable Potsdam sandstone of the region, and in a number of places sections showing most beautifully the unconformity between this sandstone and the older quartzite series are to be seen. Notable instances of such sections are the two gorges just alluded to, by which the Baraboo River passes through the northern range. At each of these points the contact between the quartzite and the sandstone filled with great rounded bowlders and smaller fragments drawn from the older formation is plainly to be seen. These points, as also numbers of other similar ones, I have described in detail in the second volume of the Geology of Wisconsin, in which I have also shown by sections and descriptions how enormous the unconformity between these two formations is; so great that the intervening period must have covered the elevation of the older series into a mountain mass thousands of feet in height, and the wearing down of this mass into the insignificant ridges upon and against which the Potsdam sandstone was deposited. These rocks were at that time referred to the Huronian of Canada, and my subsequent study of the latter formation seems to leave me no room for doubt as to the correctness of the reference.

North and east from the Baraboo ridges there protrude here and there through the horizontal sandstone of the region knobs of a felsitic porphyry and others of granite. The similarity of the porphyries of these areas with that associated with the quartzites of the Baraboo region and their geographical distribution render it evident that they mark for us an extension to the northeastward under the Potsdam sandstone of the Baraboo porphyry; while the occurrence of quartzites in the bottoms of certain artesian wells to the east and south of this porphyry belt indicate a similar northeastward extension of the Baraboo quartzite.[24] In connection with the Baraboo series, and as evidently forming part of it, should be mentioned the detached areas of quartzite of southern Dodge and northwestern Jefferson Counties, in Wisconsin.[25] Allof these areas are so thoroughly described and mapped in the Wisconsin reports, and the material from them in my hands is so plentiful, that it is not supposed that they will require any further considerable study in the field. We have already examined in connection with our general studies of quartzites a large number of thin sections of quartzite from the Baraboo region, and we expect to study hereafter also a number of sections of the porphyries.

THE QUARTZITE SERIES OF SOUTHERN MINNESOTA AND SOUTHEASTERN DAKOTA.

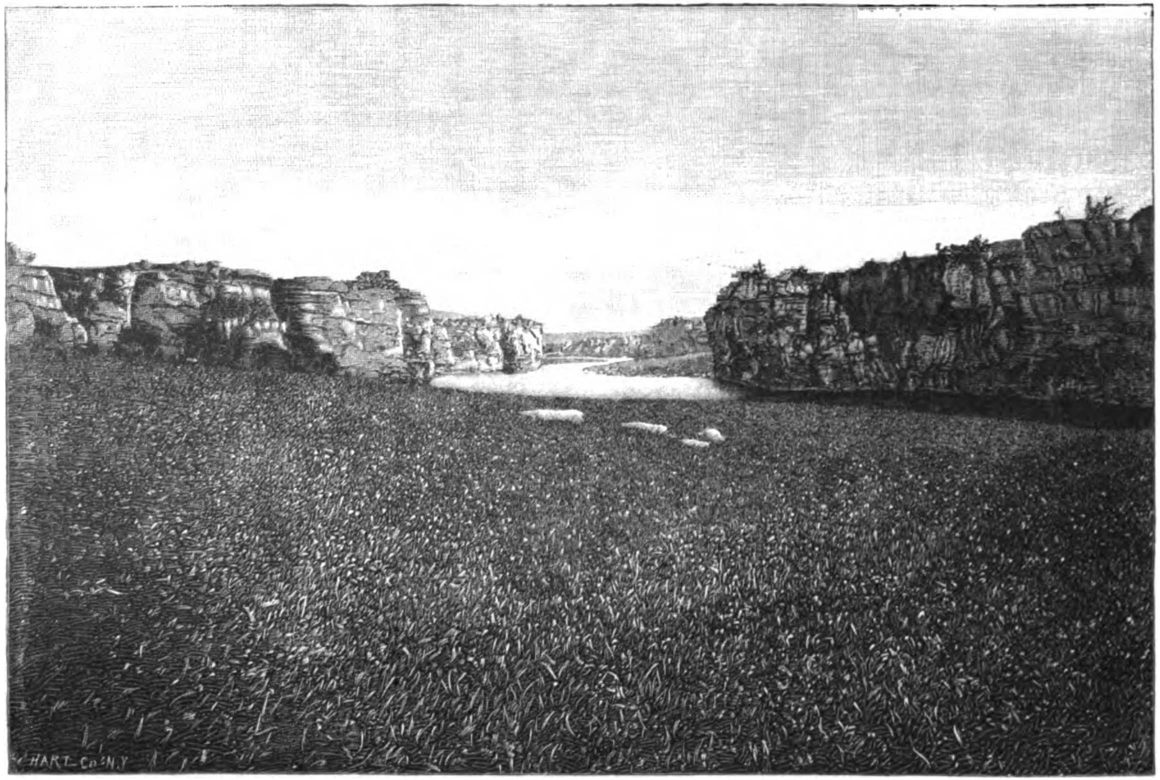
West of the 94th parallel, in Minnesota, the older formations are, for the most part, concealed by the overlying Quaternary accumulations, which include both morainic glacial depositions, and, in the Red River

[24] Geol. Wis., Vol. II, Plate XVIII.
[25] Geol. of Wis., Vol. II, pp. 252–256.

Valley, the deposits from the great lake which formerly occupied it. From beneath this Quaternary blanket here and there appear patches of Cretaceous clays and shales. Often these Cretaceous deposits are singularly intermingled with the glacial detritus, the forces by which the latter was produced having often plowed the two together. The geologists of Minnesota, who have studied these formations with much care, do not, if I understand them correctly, consider that these Cretaceous exposures indicate the present existence of a continuous sheet of Cretaceous material underneath the Quaternary deposits, but that they are the remnants of a once continuous Cretaceous sheet, which, already more or less thoroughly broken by erosion in pre-glacial times, suffered still greater destruction on account of its soft and yielding nature when invaded by the ice-sheets that produced the morainic accumulations of the region. Westward from the Red River Valley the Cretaceous exposures become more numerous, the glacial accumulations dying out, until, west of the Missouri River, the great plains are everywhere underlaid by Cretaceous or Tertiary deposits.

Returning now to central Minnesota, we find the valleys of the greater streams—as, for instance, the Minnesota River—cutting through both the Quaternary and the Cretaceous, so as to reach the still older formations. All along the valley of the Minnesota, from its head at Big Stone Lake to New Ulm, in Brown County, there are exposed gneissic and granitic rocks, which are supposed to be a direct continuation of those of the Mississippi Valley in Stearns, Morrison, Benton, Mille Lacs, Sherburne, and adjoining counties. At New Ulm and Redstone, on the Minnesota, however, are exposed reddish quartzites and conglomerates, which plainly overlie unconformably the gneiss of the upper portion of the valley. This quartzite formation, which finds its easternmost exposure at Redstone, has a wide spread in southern Minnesota and southeastern Dakota. Its northern limits, so far as can be learned by exposures, lie, in Minnesota, a few miles south of the Fort Pierre line of the Chicago and Northwestern Railway, and in Dakota on a line running from northern Moody County west-southwest to Mitchell, in Davidson County. The length of the belt within which the exposures lie, and whose course appears to be somewhat south of west, is thus something like 180 miles, while its maximum width, near the Minnesota boundary, is not far short of 50 miles.

Within this belt the quartzite formation is in large measure concealed by the overlying drift and Cretaceous, but the exposures are sufficiently frequent, and their character is sufficiently constant, to leave no doubt in the mind as to the actual continuity of the formation throughout. The series is bent into broad folds, the dip of the layers in the various exposures ranging from three to thirty degrees in different directions, and appearances are such as everywhere to suggest a formation of great thickness, one probably above rather than below 5,000 or even 6,000 feet. Along Split Rock Creek, in the vicinity of



INDURATED SANDSTONE ON THE PIPESTONE RIVER, PALISADES TOWNSHIP, MINNEHAHA COUNTY, DAKOTA—LOOKING SOUTH.

Sioux Falls, Dak., Mr. Merriam finds a nearly continuous section where the thickness cannot be less than 3,000 to 4,000 feet, while the exposures in northern Cottonwood County, Minnesota, certainly indicate a thickness of at least 1,500 feet.

Lithologically this formation ranges from loose sandstone to the hardest and most completely vitreous quartzite, the prevalent phase being a distinctly quartzitic one. The loosest and most completely indurated portions are arranged in the most irregular relations to one another. Occasionally they will be interstratified. At times the exposed portions will be completely vitrified, while below artificial openings will display an entirely loose sandstone, suggesting an induration of the exposed portions by weathering. In other cases, however, exactly the reverse of this will be met with, while very often the more and less indurated phases pass into each other laterally by rapid gradations, the two phases traversing the layers and dovetailing into each other in the most irregular manner. The prevalent color of the formation is red, but the loosest varieties are often very pale-colored, while the most vitreous kinds frequently present a very dark purple hue. In western Minnesota, and again at certain points in Dakota, there is associated with the quartzite the fine clayey rock known as pipestone or catlinite. Intermediate between this pipestone and the purely silicious quartzite, are clayey sandstones and quartzites, often of a blotched appearance, and not a little resembling, externally, certain of the Keweenawan sandstones of Lake Superior. So far as our microscopic studies have gone, however, the resemblance is chiefly external, the Keweenawan red sandstones being largely made up of felspathic fragments and fragments of felsitic porphyry and other acid rocks, while these are in the main mixtures of red clay and quartz. Conglomeratic phases of the quartzite are met with at numbers of points, but no other rocks but those already met with have been recognized in this great formation.

This formation has been quite variously placed in the geological scale. Hall has called it Huronian, Hayden Cretaceous, and the Minnesota geologists Potsdam. If I understand the latter correctly, their present position is that it is the equivalent of the Keweenaw Series of Lake Superior, both of them being taken as belonging to the epoch of the Potsdam Sandstone of New York. Unfortunately, in deciding between these opinions we have little to go upon in the way of contact with other formations. We have, indeed, a contact with the plainly older granites of the Upper Minnesota Valley, while the relations to the occasionally overlying Cretaceous are distinctly such as to prove that the reference to that formation is beyond question erroneous, but such contacts as are met with in the Baraboo and Chippewa regions in Wisconsin are here wanting. Nevertheless, that the relation to the latter formation is essentially the same in this region seems evident enough from other considerations. The Mississippi Potsdam, according to the Minnesota geologists, is traceable up the valley of the Minnesota with its usual

characteristics to the vicinity of Mankato. Only 20 miles farther up the river appear the tilted quartzites of the formation we are now considering. Their tilted position, their evident great thickness, and their lithological contrast with the Potsdam sandstone itself seem to make it evident that they are not merely a downward continuation of that formation, but, on the contrary, form a great uncomformably underlying series. This conclusion would still leave open the question as to whether they should be referred to the Keweenaw series or should be parallelized with the original Huronian. If we judge from lithological characters, the reference to the Huronian would be a much more logical one. With the quartzites of the Chippewa and Baraboo regions they have so much in common—the red color of the prevalent vitreous kinds, the irregular association of arenaceous and quartzitic portions, the pipestone and clayey quartzites—that their equivalency with those formations seems evident, while an actual continuity with them is sufficiently probable. This equivalency is also accepted by the Minnesota geologists, but they now also place the Chippewa and Baraboo quartzites with the Keweenaw series. Not to speak of the striking lithological contrasts between the latter quartzites and the Keweenawan rocks, and their evident similarity with the great quartzite masses of the type Huronian, I may merely for the present allude to the geographical position of the Chippewa quartzites, as strong evidence of their inferior position to the Keweenaw series. There seems, to me, then, little room for doubt that the Minnesota quartzites also should be taken as Huronian.

A number of notes on locations of exposures, with descriptions of those at New Ulm, are given in the Minnesota Reports, whilst Hall and Hayden have published brief accounts in regard to some of the exposures. Our own work upon the formation has included an examination by myself, in company with Professor Winchell, during the fall of 1883, of the New Ulm and Redstone localities in Brown and Nicollet Counties and of a number of localities in northern Cottonwood County; the examination by Mr. Merriam, in May and June of 1884, of most of the Dakota exposures, which he found to be far more numerous and to extend over a much wider territory than hitherto reported, and a microscopic study by Professor Van Hise and myself of a number of thin sections. The results of the latter study are given in the Bulletin No. 8 of the Survey. It may be merely mentioned in this connection that we find in this quartzite formation, and often in immediate association with each other, most beautiful illustrations of every stage of the process of induration by the deposition of interstitial silica described in the bulletin referred to and in a subsequent page of this paper. The loose sandstones of the formation are beautifully crystal-faced, and from them to the most thoroughly indurated, vitreous varieties there is every degree of induration.

ANIMIKIE ROCKS AT PARTRIDGE FALLS, PIGEON RIVER, MINNESOTA.

(The upper leap is over quartzites, dipping south, or away from the observer; the lower leap over a massive, vertically placed, east and west gabbro dike.)

THE ANIMIKIE SERIES.

This group of ro[illegible] called by H[illegible] and imposing expo[illegible] Thunder Bay, [illegible] Superior, and at the [illegible] by him as [illegible] series,[27] is descri[illegible] reports as [illegible] of that series. An [illegible] of the ground [illegible] my studies of the K[illegible] series in 188[illegible] interior position of [illegible] to the Keweenaw [illegible] scription, publish[illegible] inferior position for the [illegible] rocks [illegible] dian geologists [illegible] holding to their equiv[illegible] nian, with the Marquette and Menominee iron-[illegible] the iron bearing rocks of [illegible] Penokee-Go[illegible] from them on several other points, viz. (1) [illegible] series, which I make several times greater [illegible] them,[29] (2) as to the lithological compo[illegible] have described as composed of quartzi[illegible] slates, clay-slates, magnetitic q[illegible] of a cherty and jaspery material, wit[illegible] types of coarse gabbro and fine grained [illegible] in both interbedded and intersecting masses [illegible] (3) as to the so called "crowning overflow" [illegible] top of Thunder Cape and McKay's Mountain, w[illegible] Canadian reports as having been entirely erupted not only [illegible] accumulation of all the Animikie series, but also after the depo[illegible] and removal of thousands of feet of newer strata. [illegible] existence of such a crowning overflow I declined to believe, it appearing to me to have been made up by placing together exposures belonging to a number of different layers [illegible] imbedded at various horizons in the Animikie series.[31]

During the season of 1883, aided by Mr. Merriam, I made an exami[illegible] nation of the exposures along the coast between Grand Portage, Minnesota—the point at which the Animikie first appears on the [illegible] shore from beneath the Keweenaw Series—and Port Arthur on Thunder Bay, and also of the interior region as far westward as Lake Saganaga on the National Boundary Line. The exposures throughout this area are very fine, and are of particularly great interest in the neighborhood of Gunflint Lake. The study of this region was made after [illegible]

[27] Transactions Am. Inst. Mining Engineers, Vol. [illegible], p. 379.

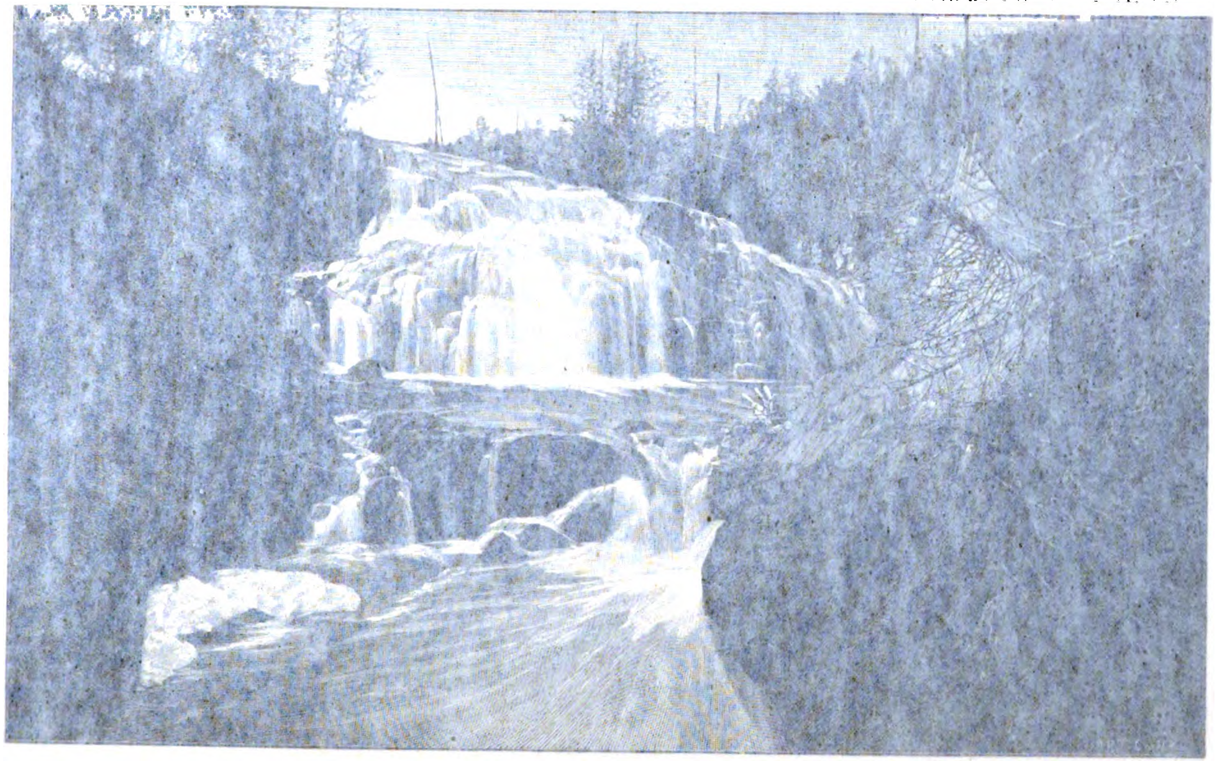
[28] Quite recently, however (" The Taconic [illegible]," Trans. Roy. Soc., Canada, Vol. I, sec. iv, p. 2[illegible]), he has [illegible] this [illegible].

[29] Third Annual Report United States Geological Survey, pp. 157-163; also, Monographs United States Geological Survey, Vol. V (1883), pp. 367, 3[illegible], 395.

[30] Op. cit., p. 379.

[31] Op. cit., p. 379-381.

[32] Op. cit., 382. Quite recently (Science No. 60, 1884) the present Director of the Canadian Survey has announced his disbelief in this "crowning overflow."



ANIMIKIE ROCKS AT PARTRIDGE FALLS, PIGEON RIVER, MINNESOTA.

(The upper leap is over quartzites dipping south [illegible]; the lower leap over a massive [illegible] [illegible].)

THE ANIMIKIE SERIES.

This group of rocks, first so called by Hunt,[26] from its well-known and imposing exposures about Thunder Bay, on the north side of Lake Superior, and at the time regarded by him as newer than the Keweenaw series,[27] is described in the Canadian reports as a downward extension of that series. An examination of the ground made in connection with my studies of the Keweenaw series, in 1880, served to assure me of the inferior position of the Animikie to the Keweenawan rocks. In my description, published as a result of that examination,[28] I maintained this inferior position for the Animikie rocks but departed from the Canadian geologists in holding to their equivalence with the original Huronian, with the Marquette and Menominee iron-bearing rocks, and with the iron bearing rocks of the Penokee-Gogebic region. I also differed from them on several other points, viz, (1) as to the thickness of the series, which I make several times greater than that assigned to it by them;[29] (2) as to the lithological composition of the series, which I have described as composed of quartzites, often arenaceous, quartz-slates, clay-slates, magnetitic quartzites, thin limestone beds, and beds of a cherty and jaspery material, with which are associated several types of coarse gabbro and fine-grained diabase in great volume and in both interbedded and intersecting masses, all of eruptive origin;[30] (3) as to the so-called "crowning overflow," shown for instance at the tops of Thunder Cape and McKay's Mountain, which is described in the Canadian reports as having been entirely erupted, not only after the accumulation of all the Animikie series, but also after the deposition and removal of thousands of feet of newer strata. In the existence of such a crowning overflow I declined to believe, it appearing to me to have been made up by placing together exposures belonging to a number of different layers interbedded at various horizons in the Animikie series.[31]

During the season of 1883, aided by Mr. Merriam, I made an examination of the exposures along the coast between Grand Portage Bay in Minnesota—the point at which the Animikie first appears on the lake shore from beneath the Keweenaw Series—and Port Arthur on Thunder Bay, and also of the interior region as far westward as Lake Saganaga on the National Boundary Line. The exposures throughout all this area are very fine, and are of particularly great interest in the neighborhood of Gunflint Lake. The study of this region was made after having

[26] Transactions Am. Inst. Mining Engineers, Vol. I, p. 339.

[27] Quite recently, however ("The Taconic question in Geology," Trans. Royal Soc., Canada, Vol. I, sec. iv, p 250), he has abandoned this position.

[28] Third Annual Report United States Geological Survey, pp. 157–163; also, Monographs United States Geological Survey, Vol. V (1883), pp. 367–386, 395.

[29] Op. cit., p. 379.

[30] Op. cit., p. 379–381.

[31] Op. cit., 382. Quite recently (Science No. 00, 1884) the present Director of the Canadian Survey has announced his disbelief in this "crowning overflow."

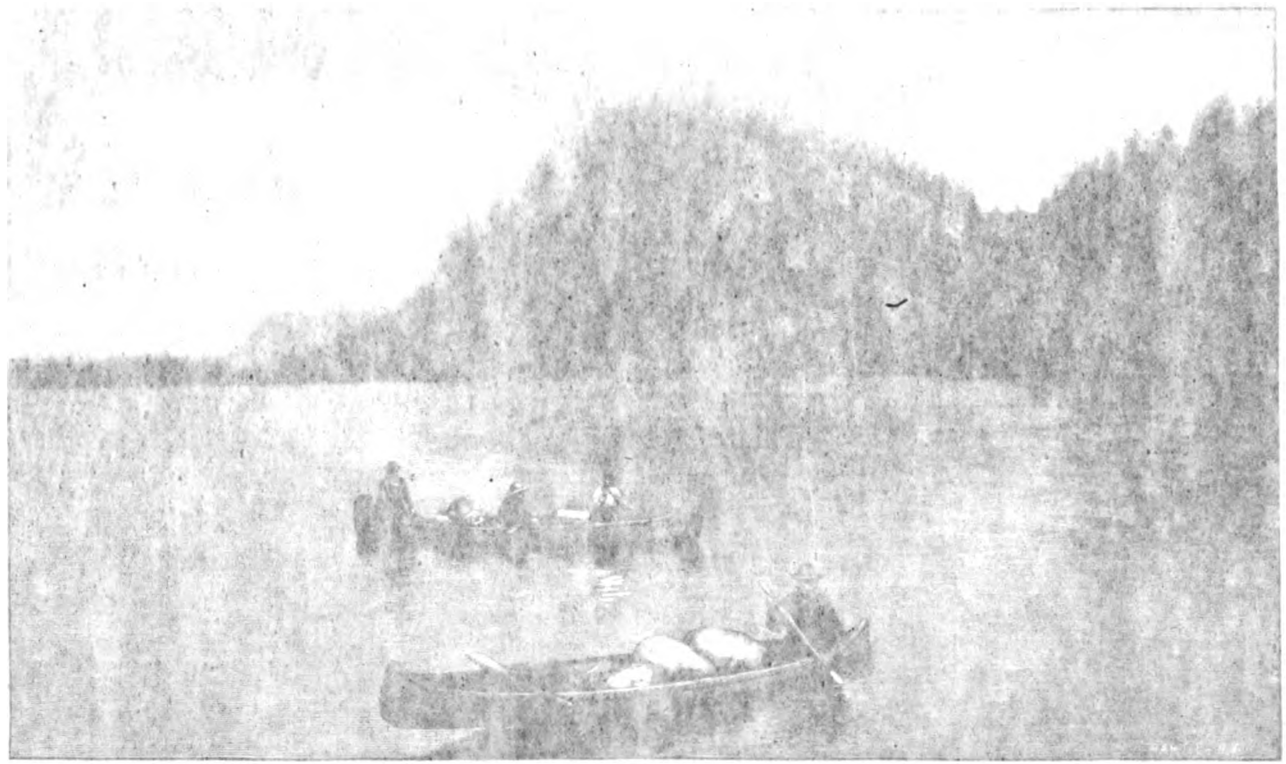
visited the north shore of Lake Huron, and served to strengthen me in the view that the Animikie series is Huronian. We found, indeed, many new points of similarity between the two formations and again between the Animikie and the South Shore iron-bearing rocks.

One of the most interesting points noted with reference to the Animikie series is the occurrence of a strongly marked continuous horizon of cherty and jaspery magnetitic schists and quartzites near the northern edge of the formation. These beds are finely displayed on the north side of Gunflint Lake, and particularly on the eastern side of Lake Saganaga. They show also in great force on the north side of North Lake on the Canadian side of the boundary line, where there are large bluffs of a jaspery rock, and again at several points in the vicinity of Thunder Bay. One of these points is alongside of the Dawson Road, immediately back of Port Arthur. The more quartzitic and arenaceous portions of these ferruginous beds present usually the ordinary flat-lying structure of the rest of the Animikie series, but the cherty and jaspery portions, frequently strongly charged with magnetic and other oxides of iron, present often peculiar irregularities and contortions in subordinate bedding, and also often a confused concretionary appearance, and even a brecciated appearance. All of these irregularities are very plainly subordinate to a simple bedding, corresponding entirely with that of the rest of the Animikie series. The jaspery ingredient constantly recalls the jaspery and cherty materials associated with the iron ores of the Marquette, Menominee, and Penokee regions, and I anticipate that when we shall have completed our microscopic studies of them we shall get from them some light as to the origin of these confused and much discussed rocks. I may now merely say that thus far the appearances are certainly in favor of the view that all of these chert and jasper schists are original, and not the result of a metamorphism upon ordinary sedimentary deposits, though manifestly they are not of eruptive origin, as has been maintained by some.

At the northwest corner of Gunflint Lake the Animikie rocks are bounded on the north by a great mass of granite. From here their northern boundary appears to extend in a southwesterly course to the Mesabi Hills, in T. 60, R. 13, W. Minn.[32]

Here reappear magnetitic quartzites similar to those of Gunflint Lake and of the Penokee Range of northern Wisconsin, and presenting the same small dip toward the basin of Lake Superior, as shown throughout the Animikie region of Thunder Bay. Still farther southwest, along the same line, after passing a long drift-covered interval, we find at

[32] For descriptions of the iron-bearing rocks of this locality, see Third Annual Report U. S. G. S., p.161, and Monographs of the U. S. Geological Survey, Vol. V, p. 382. These descriptions are based upon notes and specimens furnished by the kindness of Prof. A. H. Chester, of Hamilton College, Clinton, N. Y., who made extensive explorations for iron in this region during the summers of 1876 and 1880. Quite recently (June, 1884) Professor Chester has published a more complete account in the Eleventh Annual Report, Geological Survey of Minnesota, pp. 155–167.



[illegible] ON THE SOUTH [illegible] OF FOWL LAKE, MINNESOTA, ON THE NATIONAL BOUNDARY LINE, LOOKING EAST.

([illegible] below [illegible] rock [illegible])

[illegible] shore of Lake Huron, and served to strengthen [illegible] [illegible] the [illegible] series is Huronian. We found, indeed, [illegible] between the two formations and again [illegible] the [illegible] and the South Shore iron-bearing rocks.

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At the northwest corner of Gunflint Lake the Animikie rocks are found [illegible] north by a great mass of granite. From [illegible] their northern [illegible] appears to extend in a southwesterly course to the [illegible] [illegible], in T. 66, R. 13, W. Minn.[2]

Here reappear magnetitic quartzites similar to those of Gunflint Lake and of the Penokee Range of northern Wisconsin, and presenting the same small dip toward the basin of Lake Superior, as shown throughout the Animikie region of Thunder Bay. Still farther southwest, along the same line, [illegible] drift-covered interval, we find at

[1] For descriptions of the iron-bearing rocks of this locality, see Third Annual Report U. S. G. S., p. 161, and Monographs of the U. S. Geological Survey, Vol. V, p. 3[illegible]. These descriptions are based upon notes and specimens furnished by the kindness of Prof. A. H. Chester, of Hamilton College, Clinton, N. Y., who made extensive explorations for iron in this region during the summers of 18[illegible] and 1880. Quite recently (J[illegible], 18[illegible]) Professor Chester has published a more complete account in the Eleventh Annual Report, Geological Survey of Minnesota, pp. 15[illegible]-167.

CLIFF ON THE SOUTH SIDE OF FOWL LAKE, MINNESOTA, ON THE NATIONAL BOUNDARY LINE—LOOKING EAST.

(This cliff, of gabbro above, and slate below, is part of a long line facing north, the rocks dipping south.)

Pokegoma falls, on the Mississippi River, and again at the falls of Prairie River, near by, exposures of ferruginous quartzites, which seem to mark the horizon of the Mesabi rocks, dipping, as they do, in a similar southeastern direction. To the northwest, or behind both the Pokegoma and Mesabi localities, is found a belt of granite and gneiss. Between the Mesabi locality and the Mississippi River the country is heavily drift-covered and an entire wilderness, and, so far as our knowledge goes, we are not encouraged to hope that much can be found here to connect the rocks of these localities with each other and with the slates of the Saint Louis, which, as already indicated, are taken to belong to the same formation. Between the Mesabi Range and Gunflint Lake, however, a region almost wholly unknown to the geologist, the rock exposures are reported as frequent and often on a large scale, and the prospects are good that we shall be able to obtain in this region many facts which will much extend our knowledge of the Animikie series and will throw light upon the difficult question of its relation to the folded rocks lying further to the northwest. Unfortunately, most of this great stretch has not as yet been surveyed by the United States Land Office, and being at the same time a complete wilderness and exceedingly difficult of access, it may take two or three seasons of work to accomplish what is necessary here. Assistant Geologist Chauvenet, who has already carried the Animikie rocks over a portion of the eastern end of this gap, *i. e.*, as far as the western line of Range 5, some 12 miles southwesterly of Gunflint Lake, will extend his explorations in this region during the present season, while Mr. Merriam will work northeasterly from the vicinity of Vermillion Lake.

FOLDED SCHISTS NORTH AND EAST OF LAKE SUPERIOR.

Within the great gneissic region north and east of Lake Superior are included belts and areas of schistose and slaty rocks, all of which have been mapped and described by the Canadian geologists as Huronian. On the accompanying map I have represented all of these areas as to which I have been able to obtain any information from the latest Canadian maps. Much of this region is covered by the large Canadian maps published in 1883. These maps are based upon the field work of Robert Bell. That portion of the region not covered by them I have taken from a manuscript map furnished me by the courtesy of the director of the Canadian survey in 1881; and also based upon the work of Robert Bell. Counting northwestward from Thunder Bay, five of these belts are encountered before reaching the Lake of the Woods. The first one of these, to judge from our own examinations, does not extend into the United States, being interrupted by the granite of the Saganaga Lake region. The second one, that which crosses the boundary east of Basswood Lake, appears to be continuous with that of the Vermillion Lake country in Minnesota, which I have mapped from the explorations by Professors Chester and N. H. Winchell, and Mr. Chau-

venet. The other belts are carried by Bell's maps well to the boundary line, but for the United States side of the line we have only to aid us the accounts given in D. D. Owen's report[33] of canoe trips upon the Vermillion, Little Fork, and Big Fork Rivers. So far as one can judge from the accounts there given of the rocks exposed on those streams, none of them is crossed by one of these schistose belts.

An examination of Bell's various reports upon the region north of Lake Superior seems to make it evident that in separating the Huronian from the gneisses of the region, his only criterion has been the schistose or non-schistose character of the rocks. All rocks of strongly schistose character seem to have been regarded at once as Huronian. At times there seems to have been some difficulty, as, for instance, when mica-schists have been found to grade directly into gneisses. That some of the rocks included within Bell's schistose belts are, lithologically, like the original Huronian, there seems to be no doubt, but on the other hand, there is no reason to believe that schistose rocks do not occur as dependencies of the older gneisses. My own experience, indeed, leads me to believe that mica-schists, hornblende-schists, and chlorite schists do occur in such a relation. I regard it, then, as a question still entirely open to investigation, whether more than a small proportion of these folded schists should be referred to the Huronian, although in the present state of our knowledge it seems probable enough that a large part of them should be so referred.

Accepting for the time some of them as Huronian, we are immediately confronted with a structural problem of a good deal of difficulty, *i. e.*, the relation of these folded schists to the unfolded Animikie series. Generally, as the Animikie series is traced towards its northern border, it is found to lie against a belt of granite and gneiss. This is so along the shore of Thunder Bay and thence westward to Gunflint Lake, and is true again at the Mesabi Range and Pokegoma Falls district, in Minnesota. North of this belt of granite again come the belts of folded schists. The appearance thus presented is at first sight one of general unconformity between the flat-lying Animikie and an older series, including the gneiss and folded schists. But a closer study of the folded schists indicates, as has already been shown by Bell, Chester, Winchell, and myself, much lithological similarity between portions of them and the Animikie Series, so that a different structural hypothesis at once presents itself to the mind. This is the one that I have elsewhere illustrated and explained.[34] The hypothesis is, briefly, that the Animikie rocks were once continuous with the folded schists to the north of them, and that they are now separated merely because of the erosion of the crowns of the folds between them, the close folding of the folded schists being supposed on this view to have been produced concomitantly

[33] Geological Survey of Wisconsin, Iowa, and Minnesota (1852), pp. ——.

[34] Third Annual Report Wis. Geol. Sur., p. 171. Monographs U. S. Geol. Sur., Vol. V, pp. 399, 417.

with the broad simple bend which forms the trough of Lake Superior. On this hypothesis, the unfolded schists of the North Shore are compared with the unfolded Penokee of the South Shore, and the folded schists of the National Boundary with the folded schists of the Marquette and Menomonee regions. All are supposed to represent a great sheet of Huronian deposits, once continuously spread upon a floor of far older gneisses and schists, which have since been brought to view by folding and denudation.

This theory was presented hypothetically only, and the collection of evidence bearing upon it must evidently be one of our most important objects. With this end in view, Assistant Geologist Chauvenet began, in August and September of 1883, what it is hoped to make a pretty detailed examination of the region about Knife and Kingfisher Lakes, and thence southward. Our attention was first drawn to this region by the publications of N. H. Winchell, in which he speaks of appearances suggesting a transition from the flat-lying Animikie to the folded schists.[35]

Not only are the exposures unusually large in this vicinity, and the opportunities of getting about, on account of the numerous deeply-ramifying lakes, very good, but this appears to be the only place where the two series, whose relation it is desired to establish, come together without the intervention of the usual belt of granite and gneiss.

Mr. Chauvenet's course, in his exploration of the region, lay northward across the Keweenaw series from Grand Marais on the Minnesota coast, as far north as Town 64, thence westward along the strike of the Animikie rocks through Ranges 1, 2, 3, and 4 west; thence diagonally across the Animikie series, in Range 5, west to the folded schists in T. 65, R. 6 W. In this vicinity the various ramifications of Kingfisher and Knife Lakes were followed in detail. Thence the country was examined as far westward as Basswood Lake, R. 9 W. Thence, turning, the boundary line was followed back to Gunflint Lake, side excursions being made to the southward in the numerous branches of Knife and Saganaga Lakes. This extensive traverse enabled Mr. Chauvenet to gain a first excellent idea of the area and, in addition, especially on Kingfisher and Knife Lakes, to obtain numerous details from which to construct a detailed map of a portion of the region. During the season of 1884 he expects to return to this region and to obtain sufficient details to enable him to map it accurately. His work thus far, as also the results of our microscopic study of the specimens gathered, has tended to show that the Knife Lake schists are actually the Animikie slates in a folded condition. That the great conglomerate of Ogishkiemuncie, or Kingfisher Lake, and the alternating quartzites and greywacke-slates of Knife Lake, are strikingly like rocks seen in the Huronian, is unmistakably true. It is also true that in the vicinity of Agamok Lake the Animikie quartzites

[35] Tenth Annual Report Geol. Sur. Minn.

appear gradually to take on a folded condition. But it is thought desirable to extend in detail the mapping begun by Mr. Chauvenet over a large area before building our conclusions too confidently.

The folded schists of Knife and Kingfisher Lakes belong evidently to the Vermillion Lake band. During the coming season we shall endeavor to do something to connect the observations of Winchell and Professor Chester with those of Mr. Chauvenet on Knife and Kingfisher Lakes. It is also designed to do what is possible during the season towards getting information as to the more northern bands crossing the boundary line between Basswood Lake and the Lake of the Woods.

INVESTIGATIONS IN GRANITIC AND GNEISSIC AREAS.

With so extensive a field of operations, it has been thought best to concentrate our attention more especially upon the various schistose areas, as more promising subjects of study than the granitic and gneissic regions, leaving the rocks of the latter for the present to be studied incidentally at their contacts with the schistose rocks. These contacts are, indeed, the most important places in connection with the granitic and gneissic tracts. The Wisconsin, Minnesota, and Canada surveys have already collected much information as to the various granitic and gneissic areas, which will lessen our labor upon them very materially. One especial study of a gneissic and granitic region has been begun by Professor C. W. Hall in central Minnesota. He has already examined in considerable detail the granitic rocks in Stearns, Morrison, and Todd Counties, Minnesota, and expects during the season of 1884 to extend his study to what is supposed to be a continuation of the same granitic area in the valley of the Minnesota.

PETROGRAPHICAL STUDIES.

SYSTEMATIC MICROSCOPIC STUDIES.

Since the beginning of our work in September, 1883, lithological studies have been steadily prosecuted except when interrupted by the field work. Much microscopic work bearing upon the subject of our investigation had already been done by myself in connection with my studies of the copper-bearing rocks of Lake Superior, and by myself and Mr. Van Hise in connection with the Geological Survey of Wisconsin. In planning our microscopic studies we have thought it best, so far as practicable, to devote ourselves to one class of rocks at a time, the material being drawn from all portions of the district under survey. It has of course been necessary to do a certain amount of miscellaneous work as an accompaniment of the field studies, but in the main we have been able to devote ourselves chiefly to the study of one class of rocks at a time. The following is the classification we have adopted as convenient for the purposes of study:

(1) Quartzites and sandstones.

(2) Greywackes and greywacke-slates.

(3) Clay-slates.

(4) Jasper-schists and chert-schists, including also a large proportion of the so-called ferruginous schists of the Huronian regions.

(5) Amphibolites, including hornblende-schist, actinolite-schist, etc.

(6) Augite-schists.

(7) Chlorite-schists.

(8) Hydromica schists.

(9) Mica-schists.

(10) Gneisses.

(11) Granites.

(12) Felsites and felsitic porphyries.

(13) Greenstones, including diabases, diorites, gabbros, norites, etc.

(14) Peridotites, including serpentines.

(15) Limestones.

QUARTZITES AND SANDSTONES.

The larger part of the microscopic work thus far accomplished has been in connection with these rocks. We have studied a very large number of quartzites from all the various Huronian areas of the region under examination, as also numerous quarzites and sandstones from other formations, for the sake of comparison. An outline account of

our most important results is given in subsequent pages, in connection with the subject of secondary enlargements of mineral fragments, and an account of them including greater detail is given in Bulletin No. 8 of the Survey.

GREYWACKE AND GREYWACKE-SLATE.

These somewhat old-fashioned terms, which are now again coming into more general use are adopted here with the same signification as that given by Geikie.[35] The greywackes here included are dark-colored, compact aggregates of rounded or subangular fragments, not only of quartz but also and predominatingly of other minerals or rocks, cemented by a paste which is usually silicious, but may be of other nature. The dark color and considerable degree of induration are essential features. Very frequently a greenish color from the content of chlorite is perceptible. The greywackes grade into finer fissile varieties which are above called greywacke-slates and these again into clay-slates. There are also all sorts of gradation varieties into the most compact quartzites. Greywackes are widely distributed rocks in the various Huronian areas, being particularly prominent in the type Huronian of the north shore of Lake Huron, in the Animikie series, and in the folded schists of Knife and Kingfisher Lakes. We have studied them microscopically from all of these regions, and also from several of the other areas above enumerated. Some of our results with regard to these rocks are given in another connection on a subsequent page and more fully in the bulletin above referred to. It may be said here that these greywackes, in which quartz fragments are a subordinate ingredient, have all been more or less affected by the same silicious induration that we have found to affect the quartzites, the indurating silica occurring both as enlargements of the quartz fragments and independently of them. Accompanying this induration there has been at times also a replacement of feldspathic material by quartz, and an alteration of feldspar to chlorite, the chlorite occurring both as a pseudomorphic substitute for the feldspars and independently crystallized in the interstices of the fragments. Probably, also, the feldspar fragments have often received secondary enlargements analogous to those described in a subsequent part of the paper. By one or more of these processes these rocks have been so changed as often to present macroscopically and microscopically the appearance of more or less thorough crystallization *in situ*, and yet they are made up almost entirely of the original fragmental material, the alterations which they have undergone having been metasomatic rather than metamorphic, as the latter term is commonly understood.

CLAY-SLATES.

True clay-slates with transverse cleavage occur in the Marquette and Menominee regions, in the Saint Louis and Mississippi slate belt, and

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[35] Text Book of Geology, 1882, p. 159.

in the folded schists north of Lake Superior; but rocks entirely like these, except as to absence of transverse cleavage, are met with in most of the other Huronian areas. The only extended microscopic work yet done on any of these clay-slates is that of Wichman, on the slates of the Marquette-Menominee series. Our own studies of these rocks have not yet progressed very far. We may merely say that some of them are plainly no more than fine-grained varieties of the greywackes, in which, perhaps, the feldspathic ingredients are represented more largely by kaolinized material, whilst others occur which present distinct gradations into true mica-slates and schists, and in which at least a considerable proportion of the material is of original crystallization.

AMPHIBOLITES.

Not very many sections of hornblende-schist and rock have been examined in connection with our present work, but what we have been able to do, taken in connection with studies made previously by Wichman and ourselves for the Wisconsin State Survey, seems to point toward some conclusions of interest. (1) The so-called hornblende rocks, *i. e.*, non-schistose rocks composed mainly of hornblende, so far as our studies have gone, seem always to be changed augitic eruptives. (2) The hornblende-schists appear to fall into two classes. The first of these includes kinds whose schistose structure appears to be the result of an alteration, and which were originally also augitic eruptives. The second comprises those phases which grade into and are associated with the hornblende-gneisses. In these latter kinds, also, so far as our studies have gone, the hornblende appears always to be of a secondary nature, every phase being found between schists in which augite excludes the hornblende, and others in which the hornblende excludes the augite. (3) The so-called actinolite-schists are sometimes only the result of extreme alteration of eruptive greenstones. In all cases they seem to be the result of an extreme degree of alteration.

AUGITE-SCHISTS.

Schists in which augite takes the place of hornblende in hornblende-schist and of mica in mica-schist were found by Wichman among the rocks of the Menominee region.[36] Since then I have found such rocks very common in the upper Wisconsin Valley,[37] interstratified with and grading into an augite-gneiss. The groundmass of these rocks is chiefly quartz, and is entirely similar to that of the typical hornblende-schists and mica-schists. I have already indicated my belief that the hornblende-schists are, in part, merely altered forms of augite-schists.

CHLORITE-SCHISTS.

Schists in which a chlorite is the chief constituent occur somewhat plentifully among the older gneisses and also in the Huronian. They

[36] Geology of Wisconsin, Vol. III, p. 645.
[37] Geology of Wisconsin, Vol. IV, pp. 669, 694–696.

all appear plainly to be much-altered rocks, and our studies seem to show that they fall into three principal classes. One of these includes kinds which are the results of an extreme alteration of augitic eruptives; another, kinds which are interstratified with and grade into the older gneisses; and a third, kinds which are plainly the result of metasomatic alterations of fragmental material. Our studies of these rocks have, however, not yet gone very far.

HYDRO-MICA-SCHISTS.

It is not long since all light-colored, greasy-surfaced schists were looked upon as talcose, but it is now well known that in a large measure such rocks contain, instead of talc, a hydro-mica. These rocks are not very abundant in the region under examination. They have been described from the Menominee region by Wichman,[38] from the Penokee region by the writer,[39] and again from the iron region of Vermillion Lake, in Minnesota, by Chester,[40] and are known also to occur in other areas. In nearly all cases the hydro-mica, though giving character to the rock, is not a predominant constituent, and occurs in minute particles. There is a gradation between these hydro-mica schists and the very distinctly fragmental rocks, like clay-slate and quartzite, so that most of them are plainly of sedimentary origin; but on the other hand there are some occurrences, as, for instance, in the Vermillion Lake region, where the schists carrying a hydro-mica present the appearance of having been produced by the alteration of an eruptive felsitic porphyry. We have not as yet been able to add anything to the accounts of these rocks already published by the writers referred to.

MICA-SCHISTS.

The mica-schists of our region include two quite distinct classes.

The Huronian mica-schists, while in the thin section often without evident fragmental material, yet do at times present such material so distinctly, and, moreover, present such unmistakable transitions into distinctly fragmental rocks, that they seem in the main to be made up of the original fragmental material. Occasionally may be seen indications that the usual background of interlocking quartz areas has been produced by a secondary enlargement of quartz fragments. How far the micaceous ingredient of any of these rocks may also be of fragmental origin it is difficult to tell. That it sometimes is so we have little doubt; but, on the other hand, we have examined many sections in which it appears to be an original mineral. Andalusite and staurolite are frequent accessories of this class of mica-schists, as, for instance, in the upper mica-schist member of the Marquette and Penokee series,[41] and in the slates of the Mississippi River, in the vicinity of Little Falls, Minn.

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[38] Geology of Wisconsin, Vol. III, pp. 636–639.
[39] Geology of Wisconsin, Vol. III, pp. 111-118.
[40] Eleventh Annual Report Geological Survey Minnesota, pp. 164-166.
[41] Geology of Wisconsin, Vol. III, p. 143.

The second class of mica-schists includes those which occur with and grading into the gneisses of the older series. These are merely peculiar fine-grained varieties of the predominant gneisses with which they occur. Thus far we have not detected in them any indication of fragmental constituents. The latter class of mica-schists often contains hornblende as an accessory ingredient, and there are frequent gradations between them and the hornblende-schists, as between hornblende-gneisses and mica-gneisses.

Our studies of mica-schists thus far include certain of the former of these two classes, from the Michigamme Lake district of the Marquette region; from the Penokee series of Ashland County, Wisconsin; from the district between the Saint Louis and Moose Lake, Minnesota, and from the Mississippi River in the vicinity of Little Falls, Minn. Of the second class, those which are merely finely laminated gneisses, we have examined only those of the upper Wisconsin Valley described by us in the Geology of Wisconsin.[42]

GNEISSES.

Our studies of gneisses have not extended beyond what we have heretofore done in connection with the Wisconsin survey. Besides this, Wichman has studied a number of gneisses from the Marquette and Menominee regions, whilst a few descriptions of Minnesota gneisses are given by Streng. Enough, however, has been made known with regard to the gneisses of the region to enable us to say that they include muscovite-gneisses, muscovite-biotite-gneisses, sericite-gneisses, biotite-gneisses, hornblende-gneisses, hornblende-biotite-gneisses, augite-gneisses, and chlorite-gneisses, the several varieties being named according to the nature of that ingredient which is added in each to the constant mixture of orthoclase, plagioclase, and quartz. Between these phases there are all sorts of gradation varieties. The hornblendic, chloritic, and augitic-gneisses are abundant, but whether they together predominate over the biotite-gneisses we cannot yet say. The hornblendic and chloritic varieties seem always to have resulted from a change of the augitic kinds.

GRANITES.

The granites of our region have probably been studied microscopically less than any other group of rocks upon the foregoing list. The areas of genuine structureless granite are not very many, although at times apparently quite extensive. Wichman has described a few granites from the Menominee region,[43] Wadsworth a number from the Marquette region,[44] Van Hise a few from the upper Wisconsin Valley,[45] and Streng several from the Sauk Valley in central Minnesota. In these various descriptions there is but one point of such especial inter-

[42] Vol. IV, pp. 625–714.
[43] Geol. Wis., Vol. III, p. 619.
[44] Bull. Mus. Com. Zoo. whole series, Vol. VII, Geol. Series, Vol. I, pp. 52–58.
[45] Geol. Wis., Vol. IV, pp. 650, 655, 686–688.

est as to be worthy of note here. This is the occurrence, in some of the hornblende-granites, of an augitic ingredient, from which the hornblende may be supposed to have been derived. The hornblende-granites of the Sauk Valley, for instance, described by Streng, carry sometimes, within the hornblende, "a core which may be taken for augite";[46] while certain granites of the upper Wisconsin Valley contain hornblende and augite or diallage in such relations to each other as to leave no doubt as to the derivation of one from the other.[47]

FELSITES AND FELSITIC PORPHYRIES.

These rocks, which constitute so marked a feature of the Keweenaw series, are rare in the older formations of this region, occurring in quantity in central Wisconsin only. Elsewhere they are known only as occasional dikes. The Keweenawan porphyries are described at some length elsewhere.[48] But little work, however, has been devoted to the older porphyries. Wadsworth has described a few occurring in dike form in the Marquette region,[49] and Van Hise a number from a large area in the neighborhood of Wausau, in the Wisconsin Valley.[50] The latter has recently studied also a number of sections of the Baraboo porphyries. There is little of interest as yet attaching to the results of these studies. It may merely be said that the microscopic study seems to show all of these porphyries to be distinctly of eruptive origin, and the porphyries of the Baraboo region in central Wisconsin to differ from those of the Keweenaw series in their much darker color and in the distinctly crystalline nature of the matrix, those at Wausau being intermediate in this respect between those of the Keweenaw series and those of the Baraboo region.

GREENSTONES.

This convenient general term is used here to cover all the massive plagioclase-augite, plagioclase-diallage, plagioclase-hypersthene, and plagioclase-hornblende rocks.

Including also the greenstones of the Keweenaw series, no class of rocks in our area has received so much attention from microscopic lithologists as this. The greenstones of the Marquette-Menominee series have been described by Wright,[51] Wichman,[52] Alport, Hawes, Julien, Rutley, Törnebohm, Pumpelly,[53] and Wadsworth,[54] (all in 1880); those of

[46] Neues Jahrbuch für Mineralogie, etc., 1877, p. 240.

[47] Geol. Wis., Vol. IV, p. 662.

[48] Monogr. U. S. G. S., Vol. V, pp. 95–112.

[49] Op. cit., p. 38.

[50] Op. cit., pp. 661, 670–673.

[51] Geol. Sur. Mich. (1873), Vol. II, pp. 213–231; Geol. Wis. (1880), Vol. III, pp. 691, 697–715.

[52] Geol. Wis. (1880), Vol. III, pp. 600–656. This description really left Wichman' hands as early as 1876.

[53] Brief descriptive notes by these lithologists are incorporated in Geol. Wis., Vol. III, pp. 518–525, also 533–599.

[54] Bull. Mus. Com. Zoöl., VII, No. 1, pp. 36–49.

the Penokee Huronian area by Julien,[55] Wright,[56] and the writer[57] (all in 1880); those of central Wisconsin by Wright (1877),[58] and Van Hise (1882);[59] those of central Minnesota by Streng (1877);[60] those of the Animikie series of the north shore of Lake Superior by the writer, (1883),[61] and of the Keweenaw series by Streng (1877),[62] Pumpelly (1878[63] and 1883[64]), and the writer (1880[65] and 1883[66]).

We have ourselves also since the beginning of the present investigation given more attention to this group than to any other on the list, except the quartzites, being now engaged in a general comparative study of the greenstones of all parts of the Northwest. Our new sections include also a large number of greenstones of the original Huronian.

The most important conclusions to which our studies now point may be mentioned. Omitting the Keweenawan greenstones, those of the older formations of the region may be classed as follows:

Plagioclase-augite rocks.

Diabase (plagioclase+augite).

Olivine-diabase (plagioclase+augite+olivine).

Orthoclase-diabase (plagioclase+augite+orthoclase).

Uralitic diabase (the augite more or less altered to uralite).

Diabase-porphyrite (plagioclase+augite+non-resolvable base).

Plagioclase-diallage rocks.

Gabbro (plagioclase+diallage).

Olivine-gabbro (plagioclase+diallage+olivine).

Orthoclase-gabbro (plagioclase+diallage+orthoclase).

Uralitic gabbro (the diallage more or less changed to uralite).

Hornblende-gabbro (the diallage more or less changed to basaltic hornblende).

Plagioclase-hypersthene rocks.

Norite (plagioclase+hypersthene).

Plagioclase-hornblende rocks.

Diorite (plagioclase+hornblende).

Of these kinds the most common, considering the older formations of the whole region, is undoubtedly diabase. After this follow apparently gabbro, olivine-diabase and gabbro, uralitic diabase and diorite. Norites, *i. e.*, rocks carrying a "rhombic pyroxene," so far as our studies

[55] Geol. Wis., Vol. III, pp. 227, 231, 233-238.
[56] Op. cit., numerous places, pp. 243-301.
[57] Op. cit., numerous references, pp. 100-150.
[58] Geol. Wis., Vol. II, pp. 637-642.
[59] Geol. Wis., Vol. IV, pp. 628-714.
[60] Neues Jahrbuch, 1877, pp. 117-138; 225-235.
[61] Monogr. U. S. G. S., Vol. V, pp. 367-386.
[62] Op. cit., pp. 42-56, 113-117.
[63] Proc. Am. Acad. Sci., Vol. XIII, pp. 253-309.
[64] Geol. Wis., Vol. III, pp. 30-49.
[65] Geol. Wis., Vol. III, pp. 168-193.
[66] Monogr. U. S. G. S., Vol. V, pp. 35-91. A general review of the basic eruptives of the entire Keweenaw series.

have gone, are very rare. We have recognized them at one or two points in the Wisconsin Valley and in the type Huronian of Lake Huron. Since the discoveries by Cross, Hague and Iddings, of the widespread occurrence of hypersthene in the andesites of the Great Basin, we have been on the outlook for a similar occurrence among the corresponding ancient rocks of our region; but thus far, while some of the older work remains to be reviewed, we have found nothing to make us believe that hypersthene is common among the greenstones now under consideration.

We take all of the diorites that we have thus far examined to be altered diabases and gabbros. Streng, as long ago as 1877, suggested this with regard to the "augite-diorites" described by him from central Minnesota.[67] In 1880, I suggested the same with regard to a peculiar greenstone carrying hornblende and augite together and forming a prominent beltin Ashland County, Wisconsin. The same year Wadsworth argued that all of the hornblendic greenstones of the Marquette Huronian were originally augitic, and in 1882, in conjunction with Mr. Vanhise, I maintained the secondary origin of all the hornblende of the rocks of the Wisconsin Valley, including various greenstones. In 1883 I stated my belief in the secondary origin of all the hornblendic rocks yet studied in the northwest, including not only greenstones, but also crystalline schists and various acid eruptives. In our more recent studies abundant evidence of the truth of this generalization, as far as the greenstones are concerned, has been obtained. I do not at all intend to assert that rocks will not be met with in this region carrying a truly original hornblende, but merely that in all of the hornblendic rocks that we have yet examined the hornblende is secondary. So far as the hornblende regarded by us as secondary is in the nature of ordinary uralite, our already announced conclusion meets with a ready acceptance, but with regard to the non-fibrous, and especially the brown or basaltic hornblende, the acceptance is not by any means so ready, the criticism having been made that these cases were ones of envelopment of augite by hornblende.[68] The German authorities have not hitherto admitted the existence of a secondary brown hornblende, but our critic himself, already familiar with the largest German collections, has, after an examination of our sections containing the most noteworthy instance that we have met with of secondary brown hornblende, acquiesced in our views.

The proof that we have relied upon for the secondary origin of hornblende has consisted (1) in the peculiar intimate relation of the augite and hornblende, the two not being separated by a simple line, but dovetailing irregularly into one another; (2) the occurrence in the hornblende areas, not only of one core, but of several or many similarly oriented cores of the original augite or diallage; (3) the occurrence

[67] Neues Jahrbuch, 1877, pp. 117-138, 231-235.
[68] Neues Jahrbuch, 1883.

in the same rock of every phase of change from complete augite or diallage to complete hornblende, and (4) the nearly invariable coincidence of the occurrence of the secondary hornblende with other indications of alteration. One thing about the supposed seconaary hornblende which would tend to a belief in its originality is the frequent, though by no means invariable, individuality of the hornblende associated with an augite individual; but so strong are the other arguments in favor of its secondary nature that we are constrained to believe in the production of a single hornblende individual from a single augite.

PERIDOTITES.

These are unusual rocks in our region. They are thus far known to us in only four localities, in all of which places they seem, however, to form quite extensive masses which we believe are of eruptive origin. In each case the rock is more or less thoroughly serpentinized. Two of these localities are in the Upper Wisconsin Valley, the rocks in each case breaking through the gneisses of that region. The northernmost of these two belts is exposed along the banks of the Wisconsin river, in the vicinity of the mouth of Copper River. (Secs. 4 and 9, T. 31, R. 6 E., Wis.) The rock is very much altered, some sections showing little more than the serpentinous decomposition product, but here and there traces of the olivine are distinguishable, while large areas of enstatite are often recognizable, both macroscopically and microscopically. Fresher portions of the rock are black in color, but often large portions are changed to serpentine. Another belt, apparently quite similar to the first, although the rock is perhaps more perfectly serpentinized, occurs in the northern part of Wood County. (T. 23, R. 6 E., Wis.) This belt we have not yet examined in the field. The other two localities are at Presqu' Isle and north of Ishpeming, in the Marquette region. The Presqu' Isle locality is a classical one, and has been written about by many authorities during the last thirty years. The peridotite here, accepted by most of the older writers simply as serpentine, has overlying it a thickness of over 100 feet of the "Eastern" or Lake Superior sandstone, the question with regard to the locality with most of the writers having been the relative ages of the two rocks, a number considering the sandstone as newer, and others considering it as older and disturbed by the peridotite eruption beneath it. Mr. M. E. Wadsworth, who was the first to determine the nature of this peridotite as a lherzolite, *i. e.*, a rock originally composed of enstatite, diallage, and olivine, although now mostly altered to serpentine, has lately maintained the latter view. Our own inclination, after examining the locality carefully in the summer of 1883, is towards the former opinion. However this may be, the locality is a most interesting one as bearing upon the production of serpentine by the alteration of olivinitic rocks. The upper portion of the peridotite here is in many places completely changed to a stratiform dolomite. This dolomite has been taken by some as an over-

lying sedimentary rock, but it is evident enough that Wadsworth is right in considering it as an altered portion of the peridotite itself. The peridotite is everywhere seamed with veins carrying much dolomite, while even in the dolomite itself we found large cores of the peridotites remaining. That both serpentine and dolomite and a mixture of the two have been produced here on a large scale by the alteration of an olivinitic rock, no one, I think, can doubt after examining the locality.

The serpentine-bearing area north of Ishpeming is a large one, covering several square miles. The rocks here have been described macroscopically by Rominger.[69] We examined the localities in 1883, and found the occurrence much the same as on Presqu' Isle.

LIMESTONES.

Limestones are met with, although never in very great volume as compared with the associated rocks, in the Huronion of the north shore of Lake Huron, in the Marquette and Menominee series, in the Penokee series, in the Animikie series, and in the folded schists of the national boundary north of Lake Superior. They are often dolomitic, and sometimes carry tremolite. At times they are associated with and grade into quartzites. They have been little studied microscopically, and we are not now prepared to add anything to the few accounts of them already published.[70]

ENLARGEMENTS OF MINERAL FRAGMENTS IN CERTAIN DETRITAL ROCKS.

ENLARGEMENTS OF QUARTZ FRAGMENTS.

Historical summary.—In his address before the Geological Society of London, delivered February 20, 1880,[71] Sorby describes sands whose grains are bounded externally by crystalline faces, but have in the interior the ordinary rolled grains, the crystalline faces having been produced by a secondary deposition of quartz upon the irregular surfaces of the original grains. He shows also that the quartz coatings of these grains are in perfect "optical and crystalline continuity" with the interior fragments, each original fragment having thus been changed to a "definite crystal."

He shows further that such crystalline sands occur in the sandstones of various ages, "from the Oolites down to the Old Red," and that they

[69] Geol. Surv. Mich., Vol. IV, pp. 134–143.

[70] Wichman (Geol. Wis., Vol. III, pp. 611–613); the writer (do. III, pp. 106–108, also I, p. 359).

[71] Proc. Geol. Soc. Lond., 1880, p. 62.

are commonly little coherent, but that in some specimens "a number of grains may often be seen cohering more strongly than the rest; and these show clearly that the cavities orignally existing between the grains have been more or less completely filled with quartz. Moreover, on carefully examining the less coherent grains by surface illumination, we can see not only the planes and angles due to unimpeded crystallization but also more or less deep impressions, due to the interference of contiguous grains, thus proving conclusively that the deposition of crystalline quartz took place after the nuclei were deposited as a bed of normal sand. The very imperfect consolidation sometimes met with is, perhaps, not so very surprising when we reflect on the very small coherence of many large quartz crystals which are yet in close juxtaposition. However, it does seem probable that this crystallization of quartz sometimes contributes very materially to the cohesion of the grains in hard and compact quartzites. In such examples as the Gannister of the South Yorkshire coal-field we can see, in a thin section, that the grains fit alongside one another in a very striking manner, and it is only by extreme care that good proof can be obtained of the actual deposition of quartz between them. However, in the case of a highly consolidated sandstone from Trinidad the proof of the deposition of quartz is as complete as possible; the outline of the original grains of sand is perfectly distinct; and the cavities between them are filled with clear quartz in crystalline continuity with the contiguous grains; so that the whole is a mass of interfering crystals, each having a sand-grain as a nucleus. The rock has thus been converted into a hard quartzite, almost like a true quartz rock, but differs from such quartz rocks as those of the Scotch Highlands in containing no mica crystallized *in situ*. All my specimens of these quartz rocks are really highly quartzose mica-schists; and so far I have failed in my endeavors to trace the connection between them and true sandstones, though possibly this could easily be done in some districts which I have not examined."[72]

[72] So-called "crystallized sandstones" have been described by many writers. In Europe, Gerhard noticed them as long ago as 1816; and Voigt, Deluc, and Saussure still earlier (see Naumann's Geognosie, Vol. I, 2d edition, footnotes on pp. 530, 659). They are also mentioned in the manuals of petrography by Naumann (Geognosie, 2d edition (1858), Vol. I, pp. 529, 530, 659); Von Cotta ("Rocks Classified and Described," Lawrence's translation, 1866, pp. 296, 301); Zirkel (Lehrbuch der Petrographie, Band II, 1866, pp. 575, 589), and Von Lasaulx (Elemente der Petrographie, 1875, p. 206). None of these authorities, however, seem to have perceived that the crystal-faceted grains of these sandstones are simply enlarged fragments. On the contrary, they seem in all cases to regard such sandstones as, in a large measure at least, of some sort of original chemical origin. Naumann, for instance, says (op. cit., p. 529): "Wir müssen daher viele Sandsteine als krystallinische Kieselgesteine betrachten, und es ist noch keineswegs entschieden, wie weit die Gränzen dieser krystallinischen Sandsteine zu stecken sind." Also (op. cit., p. 530, footnote), "Die schon früher von Voigt, Z. Th. auch von Deluc und Saussure aufgestellte Ansicht, dass vieler Quarzsand aus einer chemischen Auflösung der Kieselerde durch Krystallisation enstanden sei, findet daher in diesen Sandsteinen seine völlige Bestätigung. Diess berechtigt uns aber nicht, alle Sandsteine für krystallinische Bildungen zu erklären, wie solches

In the American Journal of Science for July, 1881, A. A. Young describes a sandstone from the Potsdam of New Lisbon, Wis., in which the rolled grains are enveloped in secondary crystal-faceted quartz coatings. In the same journal for June, 1883, the writer showed that what Sorby regards as probable, viz, that the cohesion of the grains in hard and compact quartzites is due to this deposition of interstitial quartz to be certainly true in the cases of certain quartzites and mica-bearing quartz-schists of the Archæan (Huronian). He also showed that irregular areas, often of very small size, and even thin crusts due to a mere weathering, occur frequently in the Saint Peter's and Potsdam sandstones of Wisconsin, in which these sandstones have been changed to vitreous quartzite by this same mode of induration,

von Mohs und Holger geschehen ist." Zirkel (op. cit., p. 589) says: "Sehr merkwürdig sind jene um und um ausgebildeten Krystalle und krystallinischen Körner mit Flächenrudimenten von Quarz in den sog. krystallisirten Sandsteinen, von denen oben (S. 575) die Rede war. Es scheint nicht, dass solche Sandsteine eigentliche klastiche Gesteine, entstanden aus der Zusammenschwemmung von Quarzfragmenten seien, indem der wohlerhaltene Zustand der Krystalle darauf verweist, dass bei ihrer Bildung chemische Processe an Ort und Stelle gewirkt haben." Von Lasaulx, in speaking of granular crystalline quartzites, says (op. cit., p. 206): "Hierzu sind auch die sog. *krystallisirten Sandsteine* zur rechnen, und es erscheint überhaupt schwierig, diese Klasse von Quarziten von manchen klastischen Gesteinen zu trennen." It is of great interest to quote in this connection the words of Von Lasaulx immediately preceding those just quoted, as expressing the view generally held by the older German petrographers as to the originally crystalline character of quartzites: "*Körnig-krystallinischer Quarzit.* Diese Varietät kann als die typische Ausbildung dieser Klasse bezeichnet werden; dieses Gestein ist ein Aggregat lauter kleiner Quarzindividuen, die mehr oder weniger fest, aber ohne ein eigentliches Bandemittel mit einander verwachsen sind und zum Theil rundum scharf und vollkommen ausgebildete Krystallformen zeigen zum Theil nur die Gestalt unregelmässiger Körner besitzen." Daubrée also noted similar crystallized sandstones from the Vosges at an early day, and he has recently (1879) reviewed his observations, and those of Elie de Beaumont, Gutberlet, Hoffman, and Croisnier, in his "Études Synthétiques de Geologie Expérimentale" (pp. 226–230), in which he states distinctly his belief in their purely chemical origin. The Vosges sandstone, to which Sorby refers as showing particularly well the fragmental nuclei to the crystals, Daubrée cites as a typical instance of a chemically deposited sandstone. He is also disposed to connect the formation of such sandstones with porphyry eruptions, which, decomposing while yet not entirely cooled, have supplied solutions of alkaline silicates to the sea water, and from these silicates the quartz crystals have been deposited. Such a view receives no support, of course, from our own observations.

In America, crystal-bearing sandstones have been noted in the Potsdam sandstone of Wisconsin by Murrish (Bull. Wis. Acad., No. 2, p. 32; also Report Geol. Surv. Wis., 1872, p. 33), who regarded these sandstones as chemical precipitates. Dr. M. E. Wadsworth has also published a brief note on induration by atmospheric action in these same sandstones (Science, March 9, 1883, p. 146), in which he speaks of the production of quartz crystals as one result of atmospheric action. There is no evidence, however, in the note referred to, that he understood these crystals to be enlarged fragments, which was first shown by Young, as subsequently noted. The indurated crusts in the Saint Peter's and Potsdam sandstones were first described, so far as I am aware, by myself (Geol. Wis., Vol. II, 1877, pp. 564, 571, 573, 585, 589, and in numerous other places;) but neither I, nor any one else, had at that time, so far as I am aware, any conception of the peculiar nature of these vitrified crusts.

i. e., by the deposition of an interstitial quartz which has divided itself off into interlocking areas optically continuous with the original grains of quartz sand.

These observations were made in the beginning of 1883, but in ignorance of Sorby's results announced in February, 1880. Several other lithologists also had in the mean time made similar observations. In the summer of 1881 Arnold Hague and Iddings noted this form of induration in the Silurian, Devonian, and Carboniferous quartzites of the Eureka district of Nevada, and Mr. Iddings prepared some drawings at the time which will apear in Hague's monograph of that district.[73] Bonney, Phillips, and others have made similar observations in Europe.[73] The peculiar induration due to weathering had also been previously observed both in Europe[74] and in this country by the writer and others, although the exact nature of the induration appears never to have been understood.

Since the publication by the writer in the American Journal of Science, above referred to, we have been engaged in studying sandstones, quartzites, and other works from various formations, with a view of determining how widespread this mode of induration is. Our attention has been mainly turned to rocks of Pre-Cambrian age, but whenever we have been able to procure the material, we have studied also rocks of more recent formations down to the Cretaceous. From the list given below it will be seen that we have found this peculiar form of induration in rocks representing nearly all of the various Huronian areas of the Northwest, as well as in a number of quartzites and sandstones of various degrees of induration from the later formations. We have also noted a number of interesting new points in this connection.

The most important result of our study is, of course, the proving that most if not all of the ancient quartzites, as well as many of the quartziferous schists, are simply fragmental rocks composed in the main of the original fragmental material—unaltered save by some of the ordinary metasomatic processes—cemented together by a siliceous cement of secondary origin. This siliceous cement forms the only part of the rock that has crystallized *in situ*, the more or less intricate interlocking of its areas and its common optical continuity with the original quartz fragments giving rise to the deceptive appearance of complete original crystallization.

Enlargements in sandstones with crystal-faceted grains.—The least advanced condition of this process of induration is to be met with in sandstones that are quite loose, as was shown by Sorby. The rolled grains of quartz are each furnished with a border of newly deposited quartz, optically continuous with the nucleus, and furnished with more or

[73] Monogr. U. S. G. S., not yet issued.

[74] Q J. G. S., Vol. XXXIX, p. 20.

[75] A. Geikie, Text-Book of Geology, pp. 158, 333, M. E.

[76] See foot-note, p. 000.

less perfectly developed crystalline faces. At times the fragment is only partially buried by the newly deposited border, this being especially true of the more irregularly outlined grains, but usually the grain is completely, though very thinly, covered, so that we have thus formed quite perfect quartz crystals, whose greater part is in each case mainly composed of the old and worn grain. These crystal-faced borders we have observed running in thickness from films so thin as to be barely perceptible with the microscope to those 0.30^{mm} in width. The presence of these crystal faces makes the surface of the sandstone affected by this induration sparkle and glisten like a frosted surface. Such crystalline sandstones have been known for a long time, and they are common in all formations from the Archæan to the Tertiary. Indeed, since our attention was first drawn to this matter it has seemed to us as if the presence of at least some of the crystalline faces in quartzose sandstone is rather the rule than the exception. There can be no doubt that all owe their sparkling appearance to this same process of secondary enlargement of the original fragments. The crystalline faces are best developed, as already said, in loose sandstones, where the induration has not gone far enough to produce interference; but they may also coexist with a considerable degree of induration.

The crystal-faced enlargements of the fragments in such sandstones may generally be separated from the nucleal grains by the presence of films of iron oxide on the surfaces of the nuclei; by the greater freedom from inclusions of the newly deposited as compared with the nucleal quartz; by the existence of a dulled surface on the inner grain, and by rows of cavities at the junction of the new quartz with the corroded surface upon which it was deposited. Cases are met with where it is exceedingly difficult to separate the two quartzes from each other. Sorby[77] mentions as such an instance the gannister of the South Yorkshire coalfield, and in our own experience we have met with two instances, those of the Huronian sandstones of Spurr Mountain, Mich., and Penokee Gap, Wis., both of which are alluded to in the list given below.

The difficulty in all of these cases arises from the great relative purity of the original quartz particles, and the entire absence of an iron oxide coating to the nuclei, and, in the last two cases at least, from the smallness of the grains; but, in all, careful search discovers grains in which the separating lines may be perceived, and no doubt remains that in these cases also the crystals are enlargements of rounded fragments. These observations are of particular interest, since they render it evident that a completely indurated rock, apparently made up entirely of originally deposited quartz, might yet be only apparently so, the lines of separation between the new and the old material being imperceptible. In the very loose sandstones the nuclei and deposited quartz are best distinguished from one another by mounting the sand crumbled from the rock in balsam, while the crystalline faces are best seen in a dry mounting of this sand.

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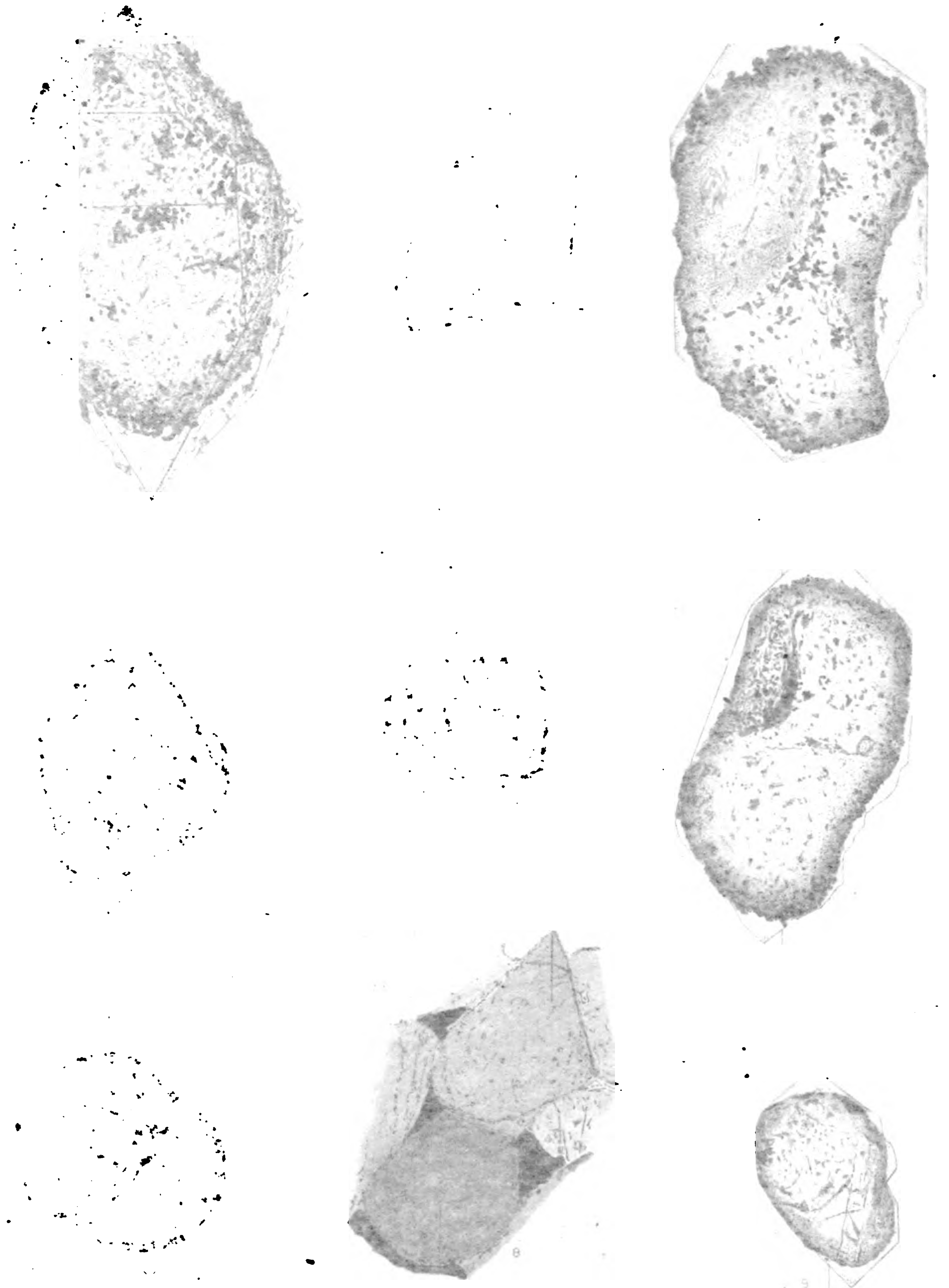
[77]Loc. cit., p. 63.



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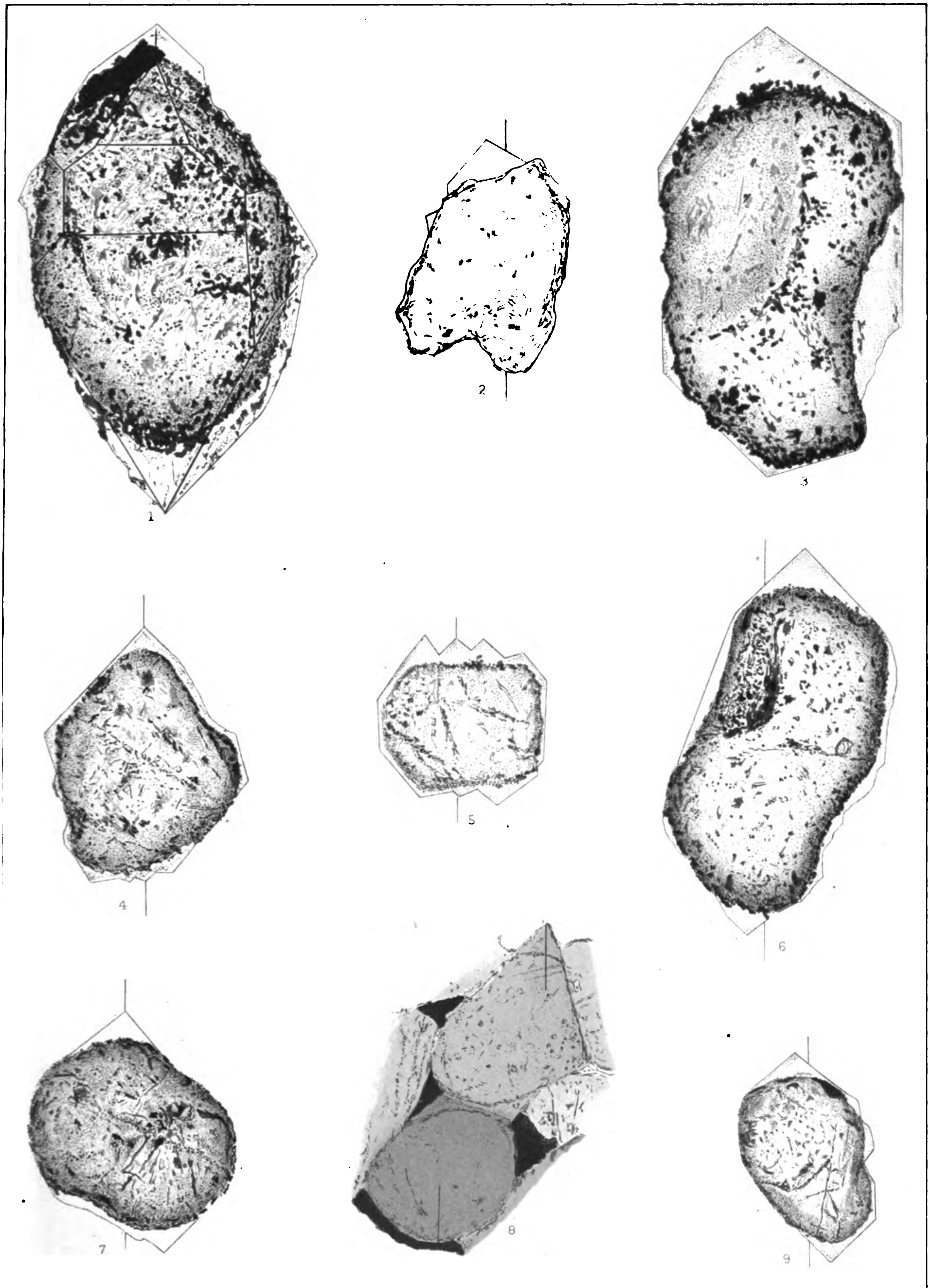


Julius Bien & C° Lith.

CRYSTAL-FACED ENLARGEMENTS OF QUARTZ FRAGMENTS.

The whole process of enlargement in these crystal-bearing sandstones is, of course, as Sorby shows[78] precisely analogous to what is well known to occur when a crystal of a soluble salt is placed in an evaporating saturated solution of the same substance. We have tried this experiment with fragments from one-eighth to one-half inch in diameter of alum, nickel ammonium sulphate, and sodium and potassium tartrate; these salts being selected simply because at hand. The fragments in each case were thoroughly rounded and coated with iron oxide. Being then hung, each in its appropriate solution, the angles and faces were soon rapidly developed, after which the crystal continued to grow over the whole surface. Sections made from these crystals showed the nuclei bounded by oxide of iron films, and built out by newly-deposited material with precisely the relations met with in the enlarged grains of crystal-bearing sandstones.

As instances of localities yielding sandstones with crystal-faceted grains, may be mentioned the following: For Huronian sandstones, East Neebish Island, Saint Mary's River, Canada; Spurr Mountain, Michigan; Penokee Gap, Ashland County, Wisconsin; Devil's Lake, Sauk County, Wisconsin, and Redstone, Nicollet County, Minnesota. For Potsdam sandstones, New Lisbon, Juneau County, Wisconsin; the great bluff known as Roche-à-Crier, Adams County, Wisconsin; and the railroad cut on the Chicago and Northwestern road just south of Madison.[79] For Saint Peter's sandstones, Arlington Prairie, Columbia County, Wisconsin.

On Figs. 1 and 2 of the accompanying Plate XXX are represented single grains, enlarged 67 diameters, of the Huronian sandstone from Neebish Island. The crystal facets of Fig. 1 were drawn with the camera lucida from the uncovered grain, after which the grain was covered with balsam, and the nucleal fragment drawn in. Fig. 2 was drawn as seen in the balsam mounting only. Fig. 3 represents a single grain of the Huronian sandstone of Spurr Mountain, Michigan, enlarged 100 diameters. Figs. 4, 5, and 6 are from balsam mountings of single grains of the Potsdam sandstone of New Lisbon, Wis., enlarged 95 diameters. Figs. 7 and 9 represent similarly mounted grains of the Potsdam sandstone of the quarry on the Torch Lake Railroad, Keweenaw Point, Mich., enlarged 67 diameters. Fig. 8 represents a portion of a thin section, enlarged 67 diameters, of the same sandstone, showing how the nucleal fragments and enlargements polarize together. The black spaces are holes in the section.

Enlargements in feebly-indurated sandstones.—A more advanced condition of induration is met with in certain sandstones, which, while

[78] Loc. cit, p. 62.

[79] This is the layer described in the Wisconsin reports under the name of the Madison sandstone. The occurrence of crystal-faceted grains in the more siliceous and looser portions of this layer appears to be an all but universal phenomenon in southern Central Wisconsin.

still showing to some extent the crystalline facets, have the secondarily deposited quartz areas more generally interfering with one another. This may be seen in much of the Huronian quartzite of Neebish Island, Saint Mary's River, Redstone, Minnesota and Devil's Lake, Wisconsin, at all of which localities may be seen rapid transitions from the loosest sandstones to the most compact and vitreous quartzite; as also in much of the Potsdam sandstone of the interior of Wisconsin, for instance the rock quarried at Grand Rapids, Black River Falls, and Packwaukee. The same thing is seen in much of the vitrified crust of the Saint Peter's sandstone of Arlington, Columbia County, Wisconsin, a thin section of which is figured at Fig. 1, Plate III, Bulletin No. 8 of the Survey. This crust is, immediately beneath the surface, without crystalline facets, the enlargements having interfered too thoroughly. But at a depth of one-fourth to one-half an inch the crystal facets begin to grow plentiful, until the loose sandstone is reached at a depth of about an inch or two, where every grain is furnished with the facets. The figure referred to shows one of the intermediate phases, where there has been some interference, but facets have been enabled to form in a number of places. The outlines of the nucleal grains are distinctly but not strongly marked.

Enlargements in arenaceous quartzites.—A yet more advanced stage of induration, but one which is still short of complete vitrification, is met with in those quartzites which, while retaining something of a granular or arenaceous appearance, are nevertheless without any of the crystalline facets, the interference of the secondary quartz areas having been general. An excellent instance of this is the sandstone from Gibraltar Bluff, Columbia County, Wisconsin. Much of a similar material occurs in the Huronian quartzites of the north shore of Lake Huron, of Marquette, Mich., and of southwestern Minnesota. The Gibraltar Bluff rock is shown as Fig. 1, Plate V, of the bulletin above referred to, which represents part of a thin section as seen in the polarized light, enlarged 35 diameters. A more arenaceous quartzite, but still one without crystal faces is shown at Fig. 2, Plate III, of the same bulletin, which represents a thin section of the sandy Animikie quartzite of Portage Bay Island, Minnesota. The enlargement is 35 diameters and the section is represented as seen in the polarized light. It will be noted that the enlargements of the grains are at times unusually broad.

Enlargements in vitreous quartzites.—In the most completely vitreous quartzites the arenaceous or granular appearance is entirely lost, the particles being fused into an apparently homogeneous mass, which appears both to the naked eye and under the microscope to be wholly composed of originally deposited, intricately interlocking areas of quartz. But closer study of the sections of such quartzites shows that, like those previously described, they are made up partly of fragmental material and partly of a secondarily deposited quartz, the interlocking areas of the latter being, in large measure, optically continuous with the

original fragments, but also, at times, in part independent of them. The degree of intricacy of the interlocking of the areas of the secondary quartz will be found to vary greatly in different quartzites. At times these areas will meet each other along quite straight or only slightly curved lines and again they will dovetail into each other in the most intricate manner. As a type of the most completely vitrified quartzites may be mentioned the gannister of Marquette, Mich., number 22 of the list below. A thin section of this rock as seen in the polarized light and enlarged 31 diameters is represented in the upper half of Fig. 3 on the accompaning Plate XXXI. It will be seen that the enlargements are often unusually broad and dovetail with each other somewhat intricately. Other vitreous quartzites are shown at Figs. 1 and 2, Plate XXXI, and the upper half of Fig. 4, Plate XXXI. Two of these figures represent the red Animikie quartzite of Prairie River Falls, Minnesota. The rock of this place is described as being much of it sandy, but the specimen furnished us by the kindness of Prof. N. H. Winchell shows a quartzite in which but little of an arenaceous texture remains. These two figures are drawn from the section as seen in the polarized light, in order that the extent of the enlargements may be seen. It will be observed that in places they dovetail quite intricately and that the outlines of the very round nucleal fragments are rendered beautifully distinct by the fringes of oxide of iron.

Induration by independently crystallized quartz.—The proportion of the infiltrated quartz which has crystallized independently of the original fragments varies very greatly in different places. At times most of it, or even all, seems to occur in this form, the interstices between the much rounded fragments being entirely filled with a secondary quartz in minute, intricately interlocking areas wholly independent of the original grains. As instances of rocks in which the independent deposition of quartz has been the chief or only mode of induration, may be mentioned the foot-wall rock of the Champion mine, Michigan, much of the quartzite of the great range immediately east of Marquette, Mich, and the red quartzite of McLennan's Landing on the north shore of Lake Huron. From these extreme cases there are all phases down to the cases where all of the secondary quartz occurs as enlargements of the original fragments. Thin sections of quartzites in which the fine interstitial quartz is present are not easily represented by figures. At the lower half of Fig. 3, Plate XXXI, an attempt is made to represent the Huronian quartz-schist from near Marquette. The section is drawn as seen in the polarized light, and is enlarged 36 diameters.

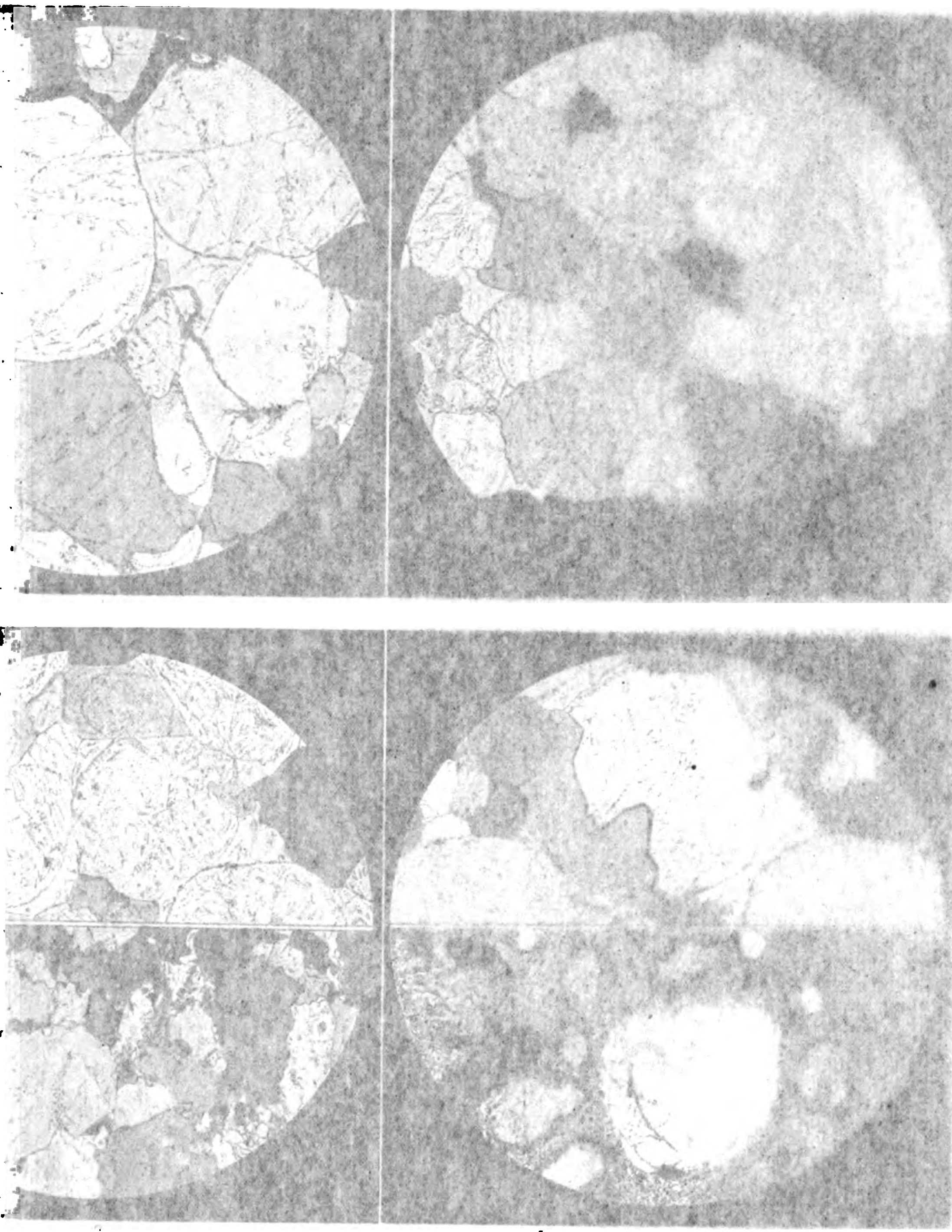
In some cases, where the enlargements of the original grains and the independently oriented quartz occur together, the enlargements present the appearance of fading out gradually into the finely interlocking interstitial material. This appearance arises from the fact that as the original fragment is receded from, less and less of the interstitial quartz is optically continuous with it, while more and more is separated out

into relatively minute and independent areas. It is thus evident that all of the interstitial quartz, including both that which is in independent areas and that which is oriented with the original fragments, has been deposited simultaneously, the crystalline influence of the fragment having lessened rapidly in power as the distance from it increased. In those cases where all of the interstitial quartz has been deposited independently of the original grains, the deposition went on too rapidly for those grains to exert their influence. The apparent fading out from quartz fragments also arises from another cause in the cases of certain certain argillaceous quartzites mentioned below.

Chalcedonic silica in quartzites.—In certain quartzites, that interstitial silica which has been deposited independently of the original fragments has in part separated out as chalcedonic or entirely amorphous silica. In fact there is every gradation found in some of these cases from that quartz which is in independent areas of some little size, through more and more finely divided kinds to that which is completely amorphous, presenting no perceptible effect when revolved between the crossed nicols. The amount of this cherty silica present varies between wide limits, in some cases predominating over the quartzose material—when the rock belongs more properly with the chert and chert-schists which are considered separately below. The lower half of Fig. 4, Plate XXXI, shows the appearance in the polarized light of a thin section of a cherty Potsdam sandstone from Westfield, Sauk County, Wisconsin, enlarged 35 diameters. Most of the rock is taken up by the cherty matrix, but in this are buried quartz fragments of various sizes which have received small enlargements. The appearance of the upper side of the largest quartz grain of the figure suggests that it may have been dissolved away.

Enlargements of complex fragments.—Commonly the quartz fragments of a sandstone or quartzite are fragments of single quartz individuals, but cases often occur where they are themselves complex, *i. e.*, made of several or many differently oriented interlocking areas. We have noted a number of cases where complex fragments have been enlarged, and in such cases the added quartz is divided off into areas oriented each with the part of the original grain with which it is in contact. This is very beautifully seen in the large grain of the upper half of Fig. 4, Plate XXXI, which is drawn from the red Animikie quartzite of Prairie River, Minnesota.

Enlargements in graywackes.—So far have been considered only rocks that are purely quartzose, or nearly so, and it is in these that the enlargement of the quartzes is most striking and generally most readily made out. But we have observed it also in a large number of rocks where the detrital material is composed more or less largely of other minerals than quartz, and even in cases where the quartz is a rather sparse accessory. A considerable part of the thickness of the original typical Huronian of Lake Huron is made up of gray to black fragmental



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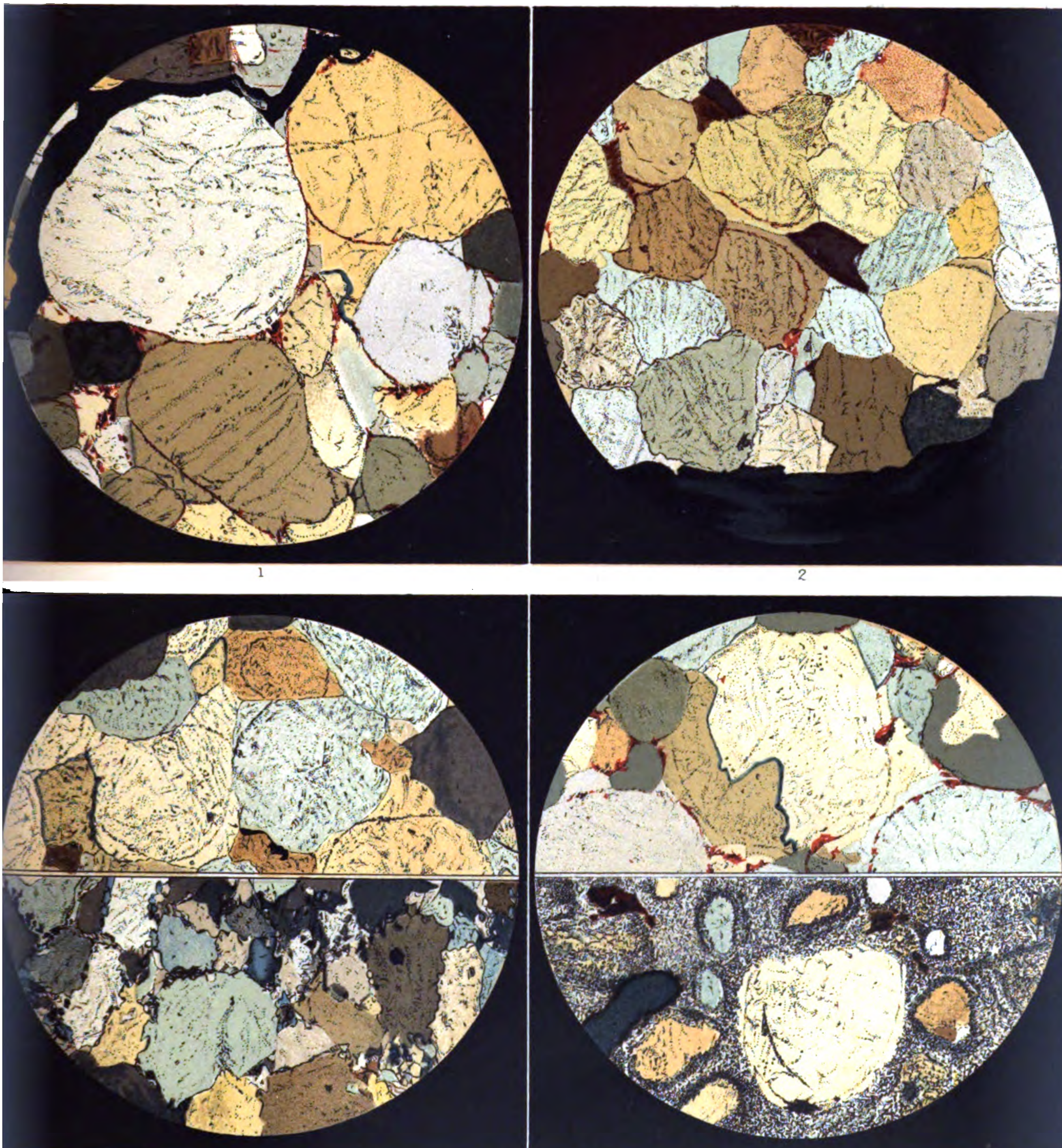

Julius Bien & Co Lith.

THIN SECTIONS OF QUARTZITES

rocks, grading from very coarse-grained kinds to those that are almost aphanitic. These rocks Logan called collectively by the name of "slate conglomerates" on account of their frequently containing pebbles of various kinds. This name, however, covers kinds which differ much from each other. Some are almost pure quartzites, with a slight admixture of feldspathic fragments. In other cases the feldspathic fragments predominate, and in the finer kinds have often been decomposed to a clayey material, when the rocks become clay-shales or slates. Most all of the kinds, except those that are nearly purely quartzose, have undergone a considerable amount of metasomatic change, the principal result of which has been the production from the feldspars of a chloritic ingredient; whence, chiefly, the dark and often greenish hue presented by these rocks.

In all of the sections of these rocks examined by us evidence has been found of the secondary deposition of interstitial quartz. In a few cases this interstitial quartz has been deposited independently of the original quartz fragments, but oftener is more or less generally co-ordinated with them. The complex character of these rocks, the metasomatic alteration which they have undergone, their dark colors, and the siliceous paste by which they have been permeated, place them among the graywackes,[80] whilst the finer-grained and more fissile kinds are graywacke-slates. These graywackes, which are, next to the quartzites, the most characteristic and important rocks of the type Huronian, are all "recomposed" rocks, and often, especially where the secondary quartz is abundant and the alteration from feldspar to chlorite has progressed far, are not far in appearance, either macroscopically or microscopically, from true crystalline rocks, and would ordinarily be classed as metamorphic. Nevertheless, they have undergone no other alteration than that which is involved in the secondary enlargement of quartz and feldspar particles, the change of feldspar to chlorite, and the interstitial deposition of independently oriented quartz; and all of these changes are such as may be met with in the more recent and so-called unaltered formations. Indeed, we may say, setting aside those changes met with in the immediate vicinity of the contact with eruptive materials, that in the typical Huronian, *i. e.*, that mapped by Logan as extending from the Saint Mary's to Blind River, on the north shore of Lake Huron, there has been no other kind of alteration of sediments than this, the various greenstone beds of the series being taken as of eruptive origin.

Graywackes and graywacke-slates, with characters in each case of their own, but in general similar to those of the Lake Huron series, we have examined from the Animikie series of the region of Thunder Bay, and thence westward along the National Boundary; from the folded slaty series of the region of Knife Lake on the boundary, and from the Huronian of the Penokee region of Wisconsin. All of these are plainly

[80] Geikie's Text-Book of Geology, p. 159.

fragmental, being composed mainly of quartz and feldspar fragments, and are permeated to a marked degree by a quartzose cement, whose areas are always more or less generally optically continuous with the original quartz particles. A belt of rocks composed of dark-colored sandstones and shales, which would come under Geikie's definition of graywackes and graywacke-slates, forms a prominent member of the Keweenaw series between Keweenaw Point and Bad River, in Wisconsin, reaching a particularly large development in the region of the Porcupine Mountains. This is the belt which I have elsewhere described under the name of the Nonesuch belt.[81] In many sections of this rock an interstitial quartz, occurring as enlargements of the original particles, is met with, and is particularly abundant in sections from that portion of the Porcupine Mountains known as the Iron River Silver Belt.[82] These graywackes, and particularly those of the silver belt just referred to, are no less metamorphic than the graywackes of the type Huronian, and yet they occur interstratified in a great thickness of unaltered sandstones. Moreover, they lie in that series many hundred feet above the latest of the great flows of eruptive material, which characterize it, so that the alteration can in no way be attributed to igneous action.

Enlargements in argillites.—Argillaceous rocks are not promising ones for the discovery of the enlargement of quartz particles, and yet we have noted in them a number of instances of such enlargements, as, for example, in the cleaved slates of the Saint Louis River region of Minnesota, and in the Marshall Hill schists of the upper Wisconsin Valley in central Wisconsin.[83] Mention has been made in a preceding paragraph of the peculiar way in which enlargements of quartz fragments in certain quartzites are made to appear as if fading off gradually into the fine interstitial material. A somewhat similar appearance, but one which is evidently due to a quite different cause, is met with in these argillaceous rocks, in which the enlargements of the widely separated quartz fragments have enveloped, in the process of growth, portions of the clayey matrix.

Enlargements in cherty rocks.—In nearly all of the schistose areas of the Northwest which have been by one or another geologist referred to the Huronian, cherty rocks, that is, rocks more or less largely composed of a chalcedonic or amorphous silica, form considerable thicknesses. They are present in the Animikie series of the Thunder Bay region, in the folded slates of the region farther north, in the original Huronian of Lake Huron, in the iron bearing series of the Marquette and Menominee regions of Michigan, and in the Penokee and Wisconsin Valley regions of Wisconsin. At least some of the jaspers associated with the jaspery

[81] Copper Bearing Rocks of Lake Superior, Monographs of the United States Geological Survey, Vol. V, pp. 220–224.

[82] Op. cit., p. 221.

[83] Geology of Wisconsin, Vol. IV, pp. 668, 681–683.

iron ores are of this nature. We are still engaged in a general study of these cherts, jaspers, &c., and are not yet prepared to give a systematic account of them. But there are several features which we have noted in regard to them that are of interest in the present connection. At times these cherts are for a considerable thickness wholly composed of chalcedonic silica, but in other cases they contain fragments of quartz in smaller or greater quantities up to a predominating amount. In such cases we have frequently noted that the quartz fragments are enlarged in the ordinary manner. These cherts, in part at least, seem to be of direct chemical origin, and the appearance in the thin sections is as if the quartz fragments had taken on enlargements of quartz simultaneously with the deposition of the mass of the amorphous silica. In these cherty rocks the enlargements of the quartz fragments present the appearance of fading away gradually into the matrix material in a manner similar to that already noted in the case of certain quartzites, where the appearance has been explained by the lessening of the crystalline influence of the original particles and the formation of more and more of independently oriented matter as they are receded from. Here, however, we find a graduation all the way from the large areas deposited so as to be optically continuous with the original quartz fragments, through a fine, interlocking, independently oriented quartz, to the chalcedonic material. There are many points as to the origin of these cherts which are yet obscure, chiefly because of the small amount of microscopic study given to them. It may, however, be taken as certain that the Huronian cherts have in considerable measure originated in the same way as the cherts of the later formations. In the Potsdam sandstone, for instance, at a number of points in the region of the upper Baraboo River, in central Wisconsin, layers of sandstone are to be noted which are highly impregnated with chert, and in which at times the chert even predominates over the sand. Chert is ordinarily thought of as characteristic of limestone formations, but the cherts of this region are wholly below and independent of any limestone formation. Evidently these cherty layers have been produced by the secondary deposition from a solution of the interstitial cherty material, and they do not appear to differ either as to the nature of the material or as to its origin from some of the true Huronian cherts. These Potsdam cherty sandstones give interesting sections, in which the interstitial, secondarily deposited material presents every degree of coarseness, from large areas optically continuous with the original quartz fragments to the finest, most completely non-polarizing, amorphous silica.

Enlargements in mica schists.—Our sections of true mica-schists are not yet very numerous, but we have found unmistakable enlargements of quartz fragments in the mica-schist forming part of the "Lower Quartzite" of Brooks, north of the Michigamme mine, Marquette region, Michigan, and in the more quartzitic portions of the upper mica-schist member (Formation XXI) of the Penokee Huronian.[84]

[84] Geology of Wisconsin, pp, 145–149.

This member of the Penokee series seems plainly to be the equivalent of the upper mica-schist member of the Marquette Huronian.[83] The latter mica-schist is finely displayed among the islands at the outlet of Michigamme Lake, where it is often plainly of an arenaceous appearance, but so far our sections have failed to prove the existence of secondary enlargements of quartz fragments in them, although what appears distinctly to be fragmental quartz is seen in these sections. The larger part, however, of the quartz present is fine and clear, so that it is difficult to determine whether it is wholly an originally deposited quartz or is a finely fragmental material, the particles of which are now so enlarged as to interlock.

A general fragmental appearance is not uncommon in other mica-schist sections that we have examined, while the presence, in some kinds at least, of very strongly marked and unmistakable deposition bandings traversing the schistose or slaty cleavage directions, is sufficient proof that in such cases the material is mainly of fragmental origin. But so far as our investigations have progressed we have only in a few cases been able to prove the enlargement of quartz fragments by secondary deposition. It seems probable, however, that in many cases where their existence cannot be proved, the enlargements exist. In such cases we may suppose that they cannot be seen, simply because of the absence of a bordering material or of roughened surfaces to the original fragments. None of the mica-schists above referred to are like those which approach the gneisses in character. The latter have as a characteristic feature large flattened areas of quartz lying in the planes of foliation. We have not as yet examined any such rocks in this connection.

LIST OF ROCKS EXAMINED.

The following is a list of the various rocks studied in this connection and found to present enlargements of the quartz fragments. Nearly every rock is represented by a number of thin sections. In the bulletin of the survey above referred to each one of these rocks has attached to it brief descriptive petrographical notes (microscopic and macroscopic).

Rocks from the typical Huronian region of Lake Huron (H).

(1.) Vitreous quartzite from island 2 miles east of Thessalon Point, north shore Lake Huron (Logan's "3 a," "Gray Quartzite").

(2.) Vitreous quartzite from islands 3½ miles northwest of Thessalon Point, north shore Lake Huron (Logan's "3 c," "White Quartzite").

(3.) Vitreous quartzite from the main-land, 4 miles northwest of Thessalon Point, north shore Lake Huron (Logan's "3 c," "White Quartzite").

(4.) Vitreous quartzite from the islands off the east point of Bruce Mine Bay, Lake Huron (Logan's "3 c," "White Quartzite").

[83] Geological Survey of Michigan, Vol. I, p. 113. Geology of Wisconsin, Vol. III, p. 165.

(5.) Vitreous quartzite from the north side of Campement d'Ours Island, Lake Huron (Logan's "3 f," "Upper Slate Conglomerate").

(6.) Vitreous quartzite from the south side of Campement d'Ours Island, Lake Huron ("3 f," "Upper Slate Conglomerate").

(7.) Vitreous quartzite from the north shore of Lake Huron, 2 miles east of McLennan's Landing (Logan's "3 f," "Upper Slate Conglomerate").

(8.) Vitreous quartzite from McLennan's Landing, north shore of Lake Huron (Logan's "3 g," "Red Quartzite").

(9.) Vitreous quartzite from 2 miles west of McLennan's Landing, north shore of Lake Huron (Logan's "3 k," "Red Jasper Conglomerate").

(10.) Vitreous quartzite from near the mouth of Echo River, Canada side of Lake George, Saint Mary's River (Logan's "3 h," "Red Jasper Conglomerate").

(11.) Vitreous quartzite from the north shore of Saint Joseph's Island, Lake Huron (Logan's "3 i," "White Quartzite").

(12.) Vitreous quartzite from east of Neebish Island Saint Mary's River (Logan's "3 i," "White Quartzite").

(13.) Vitreous quartzite from the rocky islets in Saint Mary's River, northwest of Saint Joseph's Island, Lake Huron ("3 i," "White Quartzite").

(14.) Vitreous quartzite from McDonald Township, 6 miles east of Saint Mary's River, Canada (Logan's "3 i," "White Quartzite").

(15.) Vitreous quartzite from near the mouth of Echo River, Canada side of Lake George, Saint Mary's River (Logan's "3 i," "White Quartzite").

(16.) Schistose quartzite from islands 2 miles southeast of Neebish Rapids, Saint Mary's River (Logan's "3 i," "White Quartzite").

(17.) Sandstone from East Neebish Island, Saint Mary's River (Logan's "3 i," "White Quartzite").

(18.) Graywacke from the Palladreau Islands, north shore of Lake Huron (Logan's "3 d," "Lower Slate Conglomerate").

(19.) Graywacke from the main-land 4 to 5 miles east of Campement d'Ours Island, Lake Huron (Logan's "3 f," "Upper Slate Conglomerate").

Rocks from the iron-bearing series of Marquette, Mich (H_2).

(20.) Vitreous quartzite from quartzite range south of Marquette, near shore of Lake Superior (NW. ¼ Sec. 6, T. 47, R. 24 W., Michigan). (Brooks's "Formation V, Lower Quartzite.")

(21.) Shore of Lake Superior, 2½ miles southeast of Marquette, Mich. (SE. ¼ Sec. 36, T. 48, R 25 W.). (Brooks's "Formation V, Lower Quartzite").

(22.) Vitreous quartzite from gannister quarries, north and south sides of Carp River, near Marquette (Secs. 35 and 36, T. 48, R. 25 W., Michigan). (Brooks's "Formation V, Lower Quartzite.")

(23.) Vitreous quartzite from the northwest corner of Teal Lake, Michigan. (Brooks's "Formation V, Lower Quartzite.")

(24.) Vitreous quartzite from the hanging-wall of Palmer mine, Michigan. (Brooks's "Formation V, Lower Quartzite.")

(25.) Vitreous quartzite from the hanging-wall, Saginaw mine, Negaumee district, Michigan. (Brooks's "Formation XIV, Upper Quartzite.")

(26.) Vitreous quartzite from the hanging-wall, Spurr mine, Michigamme district, Michigan. (Brooks's "Formation XIV, Upper Quartzite.")

(27.) Quartz-schist from the quartzite range south of Marquette, near shore of Lake Superior (NW. ¼ Sec. 7, T. 47, R. 24 W., Michigan.) (Brooks's "Formation V, Lower Quartzite.")

(28.) Quartz-schist from north of Michigamme mine (NW. ¼ NW. ¼ Sec. 20, T. 48, R. 30 W., Michigan). (Brooks's "Formation V, Lower Quartzite.")

(29.) Mica-schist from north of Michigamme mine (NW. ¼ NW. ¼ Sec. 20, T. 48, R. 30 W., Michigan). (Brooks's "Formation V, Lower Quartzite.")

(30.) Sandstone from a short distance north of the foot wall of Spurr mine, Michigamme district, Michigan. (Brooks's "Formation XII.")

Rocks from the iron-bearing series of the Penokee region, Wisconsin (H_3).

(31.) Vitreous quartzite from near Penokee Gap, Ashland County (NW. ¼ Sec. 14, T. 44, R. 3 W.), Wisconsin.

(32.) Vitreous quartzite from the gorge of Tyler's Fork, Ashland County (SE. ¼ NE. ¼ Sec. 33, T. 45, R. 1 W.), Wisconsin. ("Formation III.")

(33.) Vitreous quartzite from Bad River, Ashland County (SW. ¼ NW. ¼, Sec. 11, T. 44, R. 3 W.), Wisconsin. ("Formation XV.")

(34.) Vitreous quartzite from near Penokee Gap (west line of NW. ¼ Sec. 11, T. 44, R. 3 W.), Wisconsin. ("Formation XIX.")

(35.) Quartz-schist from the gorge of Tyler's Fork, Ashland County (NE. ¼ Sec. 33, T. 45, R. 1 W.), Wisconsin. ("Formation III.")

(36.) Quartz-schist from south line Sec. 2, T. 45, R. 27 W., Ashland County, Wisconsin. ("Formation XXI.")

(37.) Mica-schist from west line SW. ¼ Sec. 2, T. 44, R. 3 W., Ashland County, Wisconsin. ("Formation XXI.")

(38.) Graywacke from Tyler's Fork (NE. ¼ Sec. 28, T. 45, R. 1 W., Ashland County), Wisconsin. ("Formation XVII.")

(39.) Arenaceous quartzite from Penokee Gap, Ashland County (NE. ¼ NW. ¼ Sec. 14, T. 44, R. 3 W.), Wisconsin. ("Formation II.")

(40.) Sandstone from Mount Whittlesey, Ashland County (NW. ¼ NW. ¼ Sec. 16, T. 44, R. 2 W.), Wisconsin. ("Formation II.")

Rocks from the slates of the Saint Louis River, Minnesota (H^5).

(41.) Clay-slate from Knife Falls, Saint Louis River, Minnesota.

(42.) Clay-slate from near Mahtowah, Minn.

(43.) Clay slate from Saint Louis River, near Thompsor Minn.

Rocks from the quartzite series of the Baraboo region o Wisconsin (H_8).

(44.) Vitreous quartzite from Caledonia, Columbia County, Wisconsin.

(45.) Vitreous quartzite from the Upper Narrows of the Baraboo River, Sauk County, Wisconsin.

(46.) Vitreous quartzite from Freedom, Sauk County, Wisconsin.

(47.) Vitreous quartzite from Westfield, Sauk County, Wisconsin.

(48.) Quartz-schist from the Lower Narrows of the Baraboo River Sauk County, Wisconsin.

(49.) Quartz-schist from Ableman's, Sauk County, Wisconsin.

(50.) Quartz-schist from the Upper Narrows of the Baraboo River, Sauk County, Wisconsin.

(51.) Sandstone from Devil's Lake, Sauk County, Wisconsin.

Rocks from the quartzite series of Southern Minnesota (H_9).

(52.) Vitreous quartzite from Redstone, Nicollet County, Minnesota.

(53.) Vitreous quartzite from near New Ulm, Nicollet County, Minnesota.

(54.) Vitreous quartzite from Delton, Cottonwood County, Minnesota.

(55.) Vitreous quarzite from Mound Creek, Germantown, Cottonwood County, Minnesota.

(56.) Sandstone from Redstone, Nicollet County, Minnesota.

(57.) Sandstone from near Redstone, Nicollet County, Minnesota.

Rocks from the Animikie series of Northern Minnesota and the Thunder Bay region of Lake Superior (H_{10}).

(58.) Vitreous quartzite from Prairie River Falls (Sec. 34, T. 56, R. 25 W., Minnesota).

(59.) Vitreous quartzite from Wauswaugoning Bay, Lake Superior, Minnesota.

(60.) Vitreous quartzite from Pigeon Point, Lake Superior, Minnesota.

(61.) Arenaceous quartzite from Portage Bay Island, Minnesota, coast of Lake Superior.

(62.) Vitreous graywacke from south side of Rove Lake (NE. ¼ Sec. 28, T. 65, R. 1 E., Minnesota).

(63.) Vitreous graywacke from the east end of Mountain Lake (SW. ¼ SW. ¼ Sec. 13, T. 65, R. 2 E., Minnesota).

(64.) Vitreous graywacke from Partridge Falls, Pigeon River, Minnesota.

(65.) Vitreous graywacke from the south side of Clear Water Lake (near center Sec. 27, T. 65, R. 1 E., Minnesota).

(66.) Vitreous graywacke from the east side of Thunder Bay, Canada.

(67.) Argillaceous graywacke from Grand Portage Falls, Pigeon River, Minnesota.

Rocks from the folded schists of the national boundary line, north of Lake Superior (H_{11}).

(68.) Graywacke from King-Fisher Lake (SW. ¼ SE. ¼ Sec. 20, T. 65, R. 6 W., Minnesota).

(69.) Graywacke from King-Fisher Lake (NW. ¼ NE. ¼ Sec. 20, T. 65, R. 6 W., Minnesota).

(70.) Quartzite from Knife Lake (NW. ¼ SE. ¼ Sec. 17, T. 65, R. 6, W., Minnesota).

Keweenawan rocks.

(71.) Sandstone from Eagle Harbor, Keweenaw Point, Michigan.

(72.) Sandstone from near Copper Falls mine, Keweenaw Point, Michigan.

(73.) Sandstone from north side Portage Lake, Nonesuch Belt, Keweenaw Point, Michigan.

(74.) Sandstone from the foot-wall of the Nonesuch mine, Porcupine Mountains, Michigan.

(75.) Sandstone from the Presqu' Isle River, Michigan (NE. ¼ Sec. 5, T. 49, R. 45 W., Michigan).

(76.) Sandstone from Silver Islet Landing, north shore of Lake Superior, Canada.

(77.) Sandstone from the east side of Black Bay, Lake Superior, Canada.

(78.) Indurated sandstone from Burnt Island, Nipigon Bay, Lake Superior.

(79.) Indurated graywacke from Little Iron River (NW. ¼ NW. ¼ Sec. 12, T. 50, R. 43, Michigan).

(80.) Indurated graywacke from Little Iron River (SW. ¼ Sec. 13, T. 51, R. 42 W., Michigan).

From the "Grand Cañon Group" of the Grand Cañon of the Colorado.

(81.) Vitreous quartzite from the Grand Cañon of the Colorado, near the mouth of the Little Colorado River, Arizona.

From the Potsdam of the Mississippi Valley.

(82.) Arenaceous quartzite from immediately above the unconformable contact with the Huronian iron ores, Cyclops and Norway mines, Menominee iron region, Michigan.

(83.) Much indurated sandstone from the Lower Narrows of Baraboo River, from near contact with Archæan quartzite.

(84.) Much indurated sandstone from Roche-à-Crier, Adams County, Wisconsin.

(85.) Indurated sandstone from Packwaukee, Marquette County, Wisconsin.

(86.) Indurated sandstone from Black River Falls, Jackson County, Wisconsin.

(87.) Feebly indurated sandstone from New Lisbon, Wis.

(88.) Loose sandstone from Middleton, Dane County, Wisconsin.

From the "eastern sandstone" of Lake Superior.

(89.) Indurated sandstone from the west branch of the Ontonagon River (Sec. 13, T. 46, R. 41 W., Michigan).

(90.) Feebly indurated sandstone from the quarry on Torch Lake Railroad, Keweenaw Point, Michigan.

(91.) Red sandstone from the quarries at Marquette, Mich.

(92.) Feebly indurated sandstone from near Rockland, Mich., south of the Trap Range (SE. $\frac{1}{4}$ Sec. 7, T. 50, R. 39 W.).

From the "western sandstone" of Lake Superior.

(93.) Feebly indurated sandstone from Basswood Island, Ashland County, Wisconsin.

From the Saint Peter's sandstone of Wisconsin.

(94.) Loose sand from near Lancaster, Grant County, Wisconsin.

(95.) Indurated sandstone from Arlington Prairie, Columbia County, Wisconsin.

(96.) Indurated sandstone from Gibraltar Bluff, Columbia County, Wisconsin.

From the Paleozoic series of Eureka, Nev.

(97.) Semi-vitreous quartzite, from the "Eureka quartzite" (Silurian) Eureka, Nev.

(98.) Strongly indurated sandstone from the "White Pine shale" (Devonian) Eureka, Nev.

(99.) Feldspathic quartzite from Eureka, Nev., "Diamond Peak quartzite" (Carboniferous).

Triassic sandstone.

(100.) Feebly indurated sandstone from Henry Mountains, Utah.

Cretaceous sandstone.

(101.) Calcareous sandstone from Courtland, Nicollet County, Minnesota.

GENESIS OF HURONIAN QUARTZITES.

From the examinations above summarized we conclude that all of the quartzites of the various areas marked provisionally as Huronian on the accompanying map, including the type Huronian of Lake Huron, are merely sandstones which have received various degrees of induration by the interstitial deposition of a siliceous cement, which has generally taken the form of enlargements of the original quartz fragments, less commonly of minute independently oriented areas, and still less commonly of an amorphous or chalcedonic silica, two or even all three forms of the cementing silica occurring at times together in the same rock. There may have been in some cases some slight solution and redeposition of the original quartz material, but in the main these rocks are still made up of the fragmental constituents that composed them before induration, the fragments retaining, for the most part, their original contours. That many of these quartzites are but altered sandstones is, of course, a truth that has long been accepted; it is the nature of the alteration that has not been hitherto understood.

Without, perhaps, having been definitely so stated, the generally accepted view with regard to the production of quartzites from sandstones has included the idea of at least some molecular rearrangement of the original fragmental material,[86] quartzites having been generally classed as metamorphic, or even as crystalline rocks. So far as the Archæan quartzites of the Northwest are concerned, however, it appears that they have undergone no other alteration than that found to affect sandstones in the newer, undisturbed, and generally unaltered formations, from the Cambrian to the Cretaceous, and even certain sandbeds of the Quaternary.[87] Irregular areas, and at times mere surface films, in the otherwise unaltered horizontal Potsdam and Saint Peter's sandstones in the Mississippi Valley have been changed to vitreous quartzites, indistinguishable microscopically and macroscopically from the quartzites of the Archæan, while great beds of as completely indurated quartzites as any of the Huronian are met with in the unaltered Paleozoic formations of the West. These latter quartzites are plainly due to the percolation of silica-bearing waters, and to the same cause must be

[86] See Dana, Manual of Geology, p. 70; Geikie, Text Book of Geology, pp. 117-127; Hawes, Lithology of New Hampshire, p. 239. Hawes noticed the complex character of some of the quartz fragments of certain New Hampshire quartzites, and took it to mean that these grains had been recrystallized, rather than that they were originally complex. A very definite statement of the ordinary view as to the nature of quartzites is given by Shaler, in his "First Book in Geology," (1884) p. 238. Speaking of quartzites, he says: "In these rocks we can no longer see the distinct grains of sand, but the whole is converted into a rather solid mass of flinty matter. *The grains of sand are taken to pieces in the heated water, and remade, so that the crystals are all close set and locked together.*"

[87] Mr. J. S. Diller, of the Geological Survey, has kindly furnished me with a much indurated sandstone from the "Orange Sand" of the Mississippi Valley.

attributed the induration of the Huronian quartzites. In the case of the quartzites of the indurated portions of the Potsdam and Saint Peter's sandstones, no possible connection with any igneous action can be conceived, the surface crusts being due to a mere weathering, the interstitial silica-bearing waters having been drawn to the surface by evaporation and capillary action. These crusts are particularly interesting, because they are evidently in process of formation at the present time, occurring wherever the accidents of denudation have produced exposed surfaces of the rock, and one cannot conceive that either heat or pressure is concerned in their production, and yet they are as completely vitreous and crystalline as any of the true quartzites of the Huronian. In the case of the quartzites of the Huronian and other formations when there is much interstratified eruptive material, the latter may have been the source of the heated silica-bearing solutions, but I can see no reason to believe that there has been any other causal relation between igneous action and the induration of the sandstones than this. It is of interest to note in this connection that since the quartzites of the various Huronian areas, and, indeed, the larger part of the other non-eruptive Huronian rocks, are in no sense more altered than many fossil-bearing quartzites, etc., of later formations, it may be taken as quite certain that the failure thus far to find fossils in the Huronian is not to be attributed to their destruction by metamorphic action, but rather to the actual original barrenness of the series.

ENLARGEMENTS OF FELDSPAR FRAGMENTS IN CERTAIN KEWEENAWAN SANDSTONES.

The occurrence of enlargements of quartz fragments in quartzites and other quartz bearing fragmental rocks being proven to be a widespread phenomenon, the query arises as to whether other fragmental minerals may not have received similar enlargements.

Assistant Geologist Van Hise, in examining for me certain sandstones, has met with an answer to this query in the affirmative, so far as feldspar fragments are concerned. Besides finding what appear to be enlargements on a number of feldspar fragments in certain Huronian graywackes of the north shore of Lake Huron, he has found what are unquestionably of this nature in certain Keweenawan sandstones. A brief account of these enlargements has already been published in the American Journal of Science for May, 1884, and also in the Bulletin, No. 8, of the Survey on Secondary Enlargements of Mineral Fragments. As these results are of importance, and have a direct bearing upon our present subject, the principal paragraphs of Mr. Van Hise's paper may be appropriately quoted here:

"The feldspathic sandstone immediately underlying the diabase of Eagle Harbor, Mich., is of a reddish color, open texture, and uniform medium grain, a magnifying glass showing but little quartz. The feldspar grains are stained red with iron oxide. Hydrochloric acid gives,

with the powder, a slight effervescence. In the thin section the sandstone is seen to be composed largely of grains of different feldspars, next to which in abundance are rounded complex fragments derived from a granitic porphyry, consisting of feldspars penetrated by a saturating quartz. Then follow in order of abundance complex fragments of some altered basic rocks. Finally a few grains of quartz and a little secondary calcite are noted.

"The feldspars are frequently somewhat kaolinized, but most of the grains are fresh enough to give quite uniform colors in polarized light, and, in the cases of the plagioclases, well-defined twinning bands. The grains are all rounded, their boundaries being broad lines of ferrite. However, some subsequent mineral has used these grains as nuclei, about which to deposit, and now each individual appears in the polarized light to extend beyond its original limits. These newly-formed

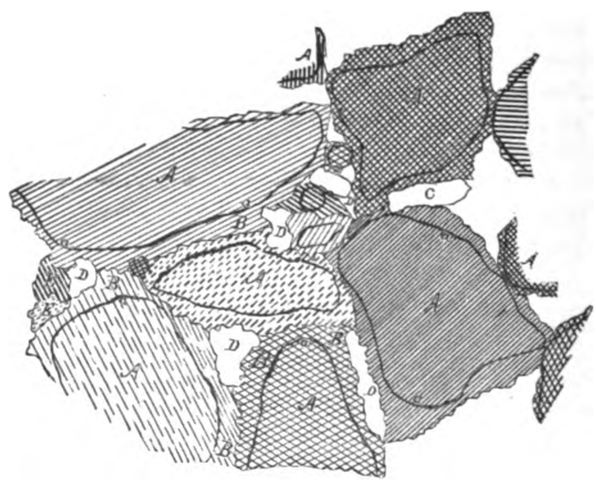

FIG. 32.—Part of section of sandstone from Eagle Harbor, Mich., × 50; in polarized light. AAA, fragments, each from a single feldspar individual; *aaa*, films of iron oxide on the borders of the original grains; BBB, secondary enlargements of the original grains; DD, unfilled spaces; EE, secondary feldspar grains polarizing independently of the original grains.

borders, as compared to the interiors, are different, in that they show no decomposition, and are freer from iron stains. When the borders from different feldspathic grains have extended so far as to come in contact, as they usually have done, they form sharply-serrate, nicely-fitting junctions, roughly comparable to the suture of a skull. (Fig. 32).

"This newly added material appears to be feldspar, which has coordinated crystallographically with the grains about which it has deposited. It possesses no optical properties which would exclude that mineral, but, cleavage and decomposition being absent, no comparison with feldspars can be made as to those characteristic features. The belief that the new material is feldspar is, however, based upon the following facts:

"When the enlarged feldspar is orthoclase the deposited substance

polarizes uniformly with the nucleus about which it is seen (Fig. 32), exactly as quartz enlargements polarize with the grains to which they have grown. Further, when plagioclase fragments present the enlargements, as they frequently do, the new material is twinned uniformly with the old, the twinning bands in polarized light running directly

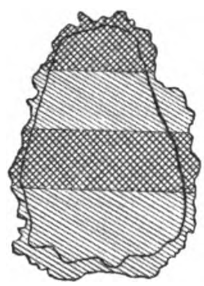

FIG. 33.—In polarized light; × 50. Plagioclase fragment from Eagle Harbor sandstone, showing crystallographic continuity of original grain and secondary en-enlargement.

FIG. 34.—In polarized light; × 50. Fragment of a granitic porphyry from Eagle Harbor sandstone. The shaded area is feldspar, the unshaded areas quartz.

across cores and borders. (Fig. 33.) This phenomenon was observed in many different grains and in different sections.

"Again, the complex fragments above mentioned as derived from a granitic porphyry, containing quartz and feldspar, often have enlargements, and the added portions resemble, and usually polarize with, the feldspars instead of with the quartz, with which they would naturally co-ordinate, if with either, were they composed of silica. Frequently the enlargements of this class of grains are apparently all of feldspar, even when a half or more of the edges of the original fragments (and in some places for considerable spaces continuously) is quartz (Fig. 3).

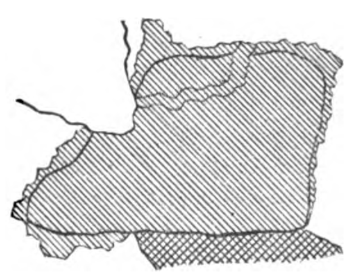

FIG. 35.—In polarized light; × 50. Part of section of Eagle Harbor sandstone, showing an orthoclase fragment broken and recemented by a secondary material crystallographically continuous with the original fragment and with the border of newly deposited material.

"Finally, the complex basic fragments also have enlargements. These basic grains are often very feldspathic, the feldspar individuals being, however, small. Here a border instead of being a unit, as it commonly is in the preceding cases, consists of several or many individuals. The feldspars at the edge of the nucleus appear to have controlled the new growth, so that the new material polarizes with them in separate parts. These parts have, however, often extended upon each side beyond the immediately adjacent feldspars of the nucleus, and thus at times overlapped other feldspars,

whose conditions were less favorable for renewed growth, or other minerals, if such chanced to be in contact with the division line between the fragment and its border.

"The change which has taken place in one grain of orthoclase is of some interest. The grain has been broken into two parts, which have spread somewhat, and is now cemented with a new material which extinguishes with the original fragments, and also with the exterior second growth with which it is continuous in places (Fig. 35.)

"In some cases the new material deposited on a grain instead of continuing as a single individual until it meets a similar growth from another grain, has crystallized independently in small interlocking grains (Fig. 32.) This independent feldspar (if I am correct in so considering it) is more plentiful about the basic fragments than about the feldspar grains or those of the granitic porphyry.

MINERAL ENLARGEMENTS IN ROCK ALTERATION GENERALLY.

The widespread importance of the enlargements of quartz fragments in the production of quartzites and other quartz-bearing indurated rocks being proved, and the existence being shown of enlargements of feldspar fragments in at least one series of sandstones, the next query is evidently whether fragments of still other minerals, each after its kind, may not have received secondary enlargements; and, if so, how far such enlargements may have been concerned in the production of the so-called metamorphic rocks. As to this, we have as yet no further facts to offer. Certainly the field is one deserving investigation. We have not studied any gneisses or similar rocks since our attention was drawn to this matter. Theoretically one can easily see how such enlargements might be of great importance in the production of gneisses and other crystalline schists, the enlargements being accompanied perhaps by partial solution of the fragmental material and by processes of replacement and pseudomorphism and by some recrystallization, pressure coming in to produce the foliation. As noted before, Bonney has already suggested the importance of this matter of enlargement of mineral fragments. His words are worth quoting in full. Speaking of certain banded crystalline schists of the Lizard district, Cornwall, England, he says: "It seems, then, possible to me that in these and in some of the curiously banded rocks in the upper group, many of the constituents may be in part original. I do not mean that any one grain as it now stands is an original constituent; crystallization *in situ*, especially in the case of the hornblende and mica, has taken place to a large extent. In the more minutely crystalline schists the original structure is very probably wholly obliterated. Still, these larger feldspar grains, for instance, may have as their nucleus feldspar grains which were original constituents, and may have survived the dissolution of the finer sedimentary materials in which they were imbedded. Then in the process of reconstitution, feldspar (not perhaps always of the same species) may

have been added to feldspar, quartz to quartz, mica to mica, and hornblende to hornblende, or altered augite. Thus traces of the minuter structure of the original rock, even in a highly metamorphosed series, may now and then remain. In those beds where the materials were finely levigated, the agents of metamorphism reduced the whole to a mere pulp (if the expression be permissible), from which the present mineral constituents crystallized, almost as they would do from the magma of an igneous rock, but in other cases only a portion of the material was reduced to this condition, and those constituents which remained undigested would form nuclei, around which the other minerals would crystallize, and would so continue to bear testimony to the original history of the rock itself. Thus the explanation of those granitoid bands, in some cases so curiously like granite veins, may be that originally they were a coarse quartz-feldspar grit. As regards some of the hornblende schists (as I believe Professor Jukes has elsewhere done), one would suggest the possibility of their having been basaltic tuffs, with which in chemical composition they would agree fairly well.

"I have ventured on this discussion because these Cornish rocks have presented structures which seem to me worthy of careful consideration by all who are studying the phenomena of metamorphism—a subject which has occupied my attention for some years past. The observations are not entirely new. Dr. Sorby drew attention to somewhat similar structures in his very valuable and suggestive paper on the original constitution and subsequent alteration of mica-schist. The agglutination of identical mineral matter has been noticed in the case of quartz, by that author, by Mr. J. A. Phillips, and by myself, independently, not to mention others In the gneissic series traversed by the upper part of Saint Gothard Pass, and in other districts, I have repeatedly noticed similar instances, all tending to show that the minute structures, and in some cases very probably the original constituents (at any rate as nuclei), may be preserved in rocks which are metamorphic in the fullest sense of the word."[88]

METAMORPHISM IN THE HURONIAN.

In the various Huronian areas above provisionally enumerated, one or more of quartzites, greywackes, and clay slates, with intermediate phases, make up the most of the series. The quartzites are but indurated quartzose sandstone, the greywackes fragmental rocks composed chiefly of other minerals than quartz and affected by a similar induration and by some slight metasomatic changes; while the clay-slates are as distinctly finer fragmental material. It thus follows that the rocks which form the bulk of the Huronian in all areas do not prop-

[88] Q. J. G. S., Feb. 1, 1883, Vol. XXXIX, pp. 18, 19.

erly fall under the head of metamorphic rocks. Of the remaining rocks met with in these areas, the various augitic and hornblendic greenstones, peridotites and felsitic porphyries I now look upon as in all probability of eruptive origin. There remain to be accounted for the various hornblende-schists, chlorite-schists, mica-schists, hydromica-schists jaspery and chert rocks and limestones. As stated above, the chloritic and hornblendic schists I regard as in part the products of the alteration of basic eruptives, and the hydromica schists, of acid eruptives. The chert and jaspery rocks I am inclined to look upon as of some sort of original chemical origin; certainly they are not the results of a metamorphism of sedimentary material. The limestones do not, as far as I know them, appear in any essential respect different from many met with in the unaltered formations of later date. There remain the mica-schists and slates, and some of the hydromica-schists and chlorite-schists. That these latter often contain much of the original fragmental material we have satisfied ourselves, but how far those of their constituents which are plainly of original crystallization were so crystallized when the rocks were in the state of mud, or have been produced by purely pseudomorphic change upon fragmental material, or how far finally they may be the result of a genuine recrystallization or metamorphism, are questions for which I have no answer. However they may be answered, it seems to me that it will remain true that the various formations here classed as Huronian, including the original type Huronian, are in the main not properly strongly metamorphic formations, as, for instance, the older gneisses must be, if of sedimentary origin.

THE GIGANTIC MAMMALS

OF THE

ORDER DINOCERATA.

BY

PROFESSOR O. C. MARSH.

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THE GIGANTIC MAMMALS OF THE ORDER DINOCERATA.

By Professor O. C. Marsh.

INTRODUCTION.

The Rocky Mountain region during Tertiary time was the home of many strange animals, quite unlike those now living in any part of the world, and perhaps the most remarkable of these extinct forms were the huge mammals of the order *Dinocerata*. The fossil remains of this group have hitherto been found in a single Eocene lake-basin in Wyoming, and none are known from any other part of this country or from the Old World. These gigantic beasts, which nearly equaled the elephant in size, roamed in great numbers about the borders of the ancient tropical lake, in which many of them were entombed.

This lake-basin, now drained by the Green River, the main tributary of the Colorado, slowly filled up with sediment, but remained a lake so long that the deposits formed in it, during Eocene time, reached a vertical thickness of more than a mile. The Wasatch Mountains on the west and the Uinta chain on the south were the main sources of this sediment, and still protect it, but the Wind River range to the north, and other mountain elevations, also sent down a vast amount of material into this great fresh-water lake, then more than 100 miles in extent.

At the present time, this ancient lake-basin, now 6,000 to 8,000 feet above the sea, shows evidence of a vast erosion, and probably more than one-half of the deposits once left in it have been washed away, mainly through the Colorado River. What remains forms one of the most picturesque regions in the whole west, veritable *mauvaises terres*, or bad lands, where slow denudation has carved out cliffs, peaks, and columns of the most fantastic shapes and varied colors. This same action has brought to light the remains of many extinct animals, and the bones of the *Dinocerata*, from their great size, naturally first attract the attention of the explorer.

The first remains of the *Dinocerata* discovered were found by the writer, in September, 1870, while investigating this Eocene lake-basin, which had never before been explored. Various remains of this group were also collected by other members of the expedition, and among the specimens thus secured was the type of *Tinoceras anceps*, described

by the writer in the following year. In the same geological horizon with these remains a rich and varied vertebrate fauna, hitherto unknown, was found.

Among the animals here represented were ancestral forms of the modern horse, and tapir, and also of the pig. Many others were found related to the recent lemurs; also various carnivors, insectivors,

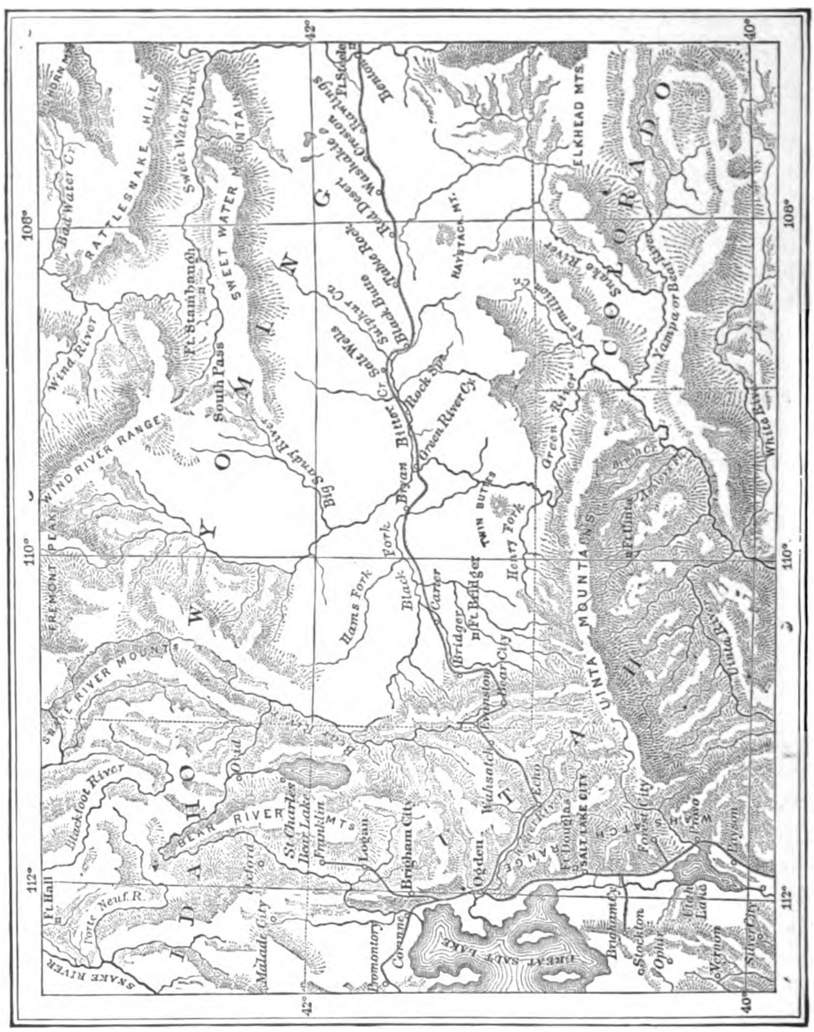


Fig. 36.—Map showing region of *Dinoceras* beds.

rodents, and small marsupials; and, of still more importance, remains were here brought to light of another new order of mammals, the Tillodonts, quite unlike any now living. Crocodiles, tortoises, lizards, serpents, and fishes also swarmed in and about the waters of this ancient lake, while around its borders grew palms and other tropical vegetation.

The present bed of this old Eocene lake-basin, in which alone the

Dinocerata had been found, offered so inviting a field for exploration that in the spring of the following year, 1871, the writer began its systematic investigation. An expedition was again organized, with an escort of United States soldiers, and the work continued during the entire season. Among the very large collections thus secured were numerous specimens of the *Dinocerata*, which furnished important characters of the group.

In the succeeding spring, 1872, the explorations in this region were continued, and soon resulted in the discovery of the type specimen, including the skull and a large portion of the skeleton of *Dinoceras mirabile*, and on this new genus the writer based the order *Dinocerata*.[1] Other important specimens obtained at this time and described by the writer were the types of *Tinoceras lacustre*, *Tinoceras grande*, *Dinoceras lucare*, and others of scarcely less interest.

In the following season, 1873, the writer organized another large expedition, with Government escort, and made a very careful examination of the regions in this same basin that remained unexplored. One of the specimens of special importance thus secured was the type of *Dinoceras laticeps*, with the skull and lower jaw nearly complete. Many other individuals of the *Dinocerata* were also discovered, and the abundant material then collected was sufficient to clear up most of the doubtful points in this group.

The research was continued systematically during the next season, also, 1874, and again in 1875, with good results. Since then, various small parties, at different times, have been equipped and sent out by the writer to collect in this basin; and, finally, during the entire season of 1882 the work was vigorously prosecuted under the direction of the writer, and, from July of that year, under the auspices of the United States Geological Survey.

The specimens thus brought together by all these various expeditions and parties are now in the museum at Yale College, and represent more than two hundred individuals of the *Dinocerata* alone. Of these, not less than seventy-five have portions of the skull more or less perfectly preserved, and in more than twenty it is in good condition. The present article is based on this material, amply sufficient, it is believed, to illustrate all the more important parts of the structure of this remarkable group.

The remaining material of the *Dinocerata*, now known, consists of a few specimens collected by Leidy in 1872, including the type of the genus *Uintatherium*; various remains secured in the same year by Cope, to which he applied the names *Loxolophodon*[2] and *Eobasileus*, with possibly a later acquisition, of uncertain affinities, called *Bathyopsis*;

[1] For full description of this order, see the author's monograph on the DINOCERATA, 56 plates. 4to. Washington, 1884.

[2] This name was first given to a specimen of *Coryphodon*, and hence cannot be used, except as a synonym, for any of the *Dinocerata*.

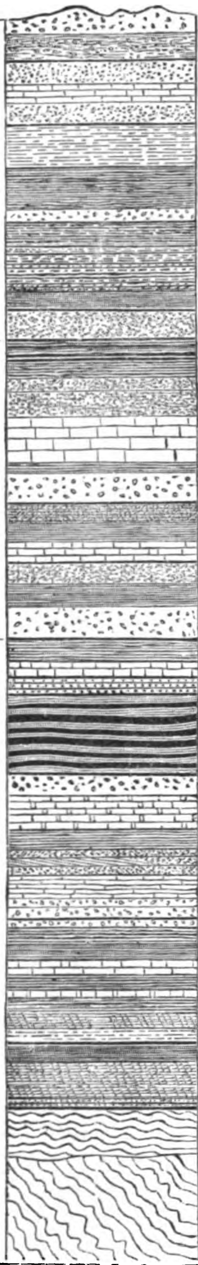
and a number of specimens more recently obtained by parties from Princeton College. These remains apparently show no characters of the *Dinocerata* not well represented in the larger collection of the Yale Museum.

The *Dinocerata* have hitherto been found in a well-marked geological horizon of the middle Eocene. The relations of this horizon to other deposits of Tertiary age are important, and cannot readily be understood without having in mind the principal changes that took place in the geology of the Rocky Mountain region during this period. These changes and their results may be briefly stated as follows:

The Tertiary of Western America comprises the most extensive series of deposits of this age known to geologists, and important breaks in both the rocks and the fossils separate it into three well-marked divisions. These natural divisions are not the exact equivalents of the Eocene, Miocene, and Pliocene of Europe, although usually so considered, and known by the same names; but in general the fauna of each appears to be older than that of its corresponding representative in the other hemisphere; an important fact, but little recognized. This partial resemblance of our extinct faunas to others in regions widely separated, where the formations are doubtless somewhat different in geological age, is precisely what we might expect, if, as was probable, the main migrations took place from this continent. It is better at once to recognize this general principle, rather than attempt to bring into exact parallelism formations that were not contemporaneous.

The fresh-water Eocene deposits of our Western Territories, which are in the same region at least two miles in vertical thickness, may be separated into three distinct subdivisions. The lowest of these, resting unconformably on the Cretaceous, has been termed the Vermilion Creek, or Wasatch, group. It contains a well-marked mammalian fauna, the largest and most characteristic genus of which is the ungulate *Coryphodon*, and hence the writer has called these deposits the Coryphodon beds. The middle Eocene strata, which have been termed the Green River and Bridger series, have been designated by the writer the Dinoceras beds, as the gigantic animals of this order are only found here. It is, however, better to separate the Green River series, under the term "Heliobatis beds," and this is done in the present article. The name "Dinoceras beds" will then apply to the Bridger series alone. The uppermost Eocene, or the Uinta group, is especially well characterized by large mammals of the genus *Diplacodon*, and hence termed by the writer Diplacodon beds. The fauna of each of these three subdivisions was essentially distinct, and the fossil remains of each were entombed in different and successive ancient lakes.

It is important to remember that these Eocene lake-basins all lie between the Rocky Mountains on the east and the Wasatch Range on the west, or along the high central plateau of the continent. As these



Era	Period		Beds	Vertebrates
Cenozoic.	Recent. Quaternary.			Tapir, Peccary, Bison, Llama. *Bos, Equus. Megatherium, Mylodon.*
	Tertiary.	Pliocene.	Equus Beds.	*Equus, Tapirus. Elephas.*
			Pliohippus Beds.	*Pliohippus, Tapiravus, Mastodon, Protohippus, Procamelus, Aceratherium, Bos. Morotherium.*
		Miocene.	Miohippus Beds.	*Miohippus, Diceratherium, Thinohyus.*
			Oreodon Beds.	*Oreodon, Eporeodon, Hyænodon, Hyracodon,* Edentates (*Moropus*).
			Brontotherium Beds	*Brontotherium, Menodus, Mesohippus, Elotherium.*
		Eocene.	Diplacodon Beds.	*Diplacodon, Epihippus, Amynodon.*
			Dinoceras Beds.	*Dinoceras, Tinoceras, Uintatherium, Limnohyus, Palæosyops, Orohippus, Helaletes, Hyrachyus, Colonoceras.*
			Green River, or Heliobatis, Beds.	*Heliobatis, Amia, Lepidosteus.*
			Coryphodon Beds.	*Coryphodon, Eohippus.* Lemurs, Carnivores, Ungulates, Tillodonts, Rodents, Serpents.
Mesozoic.	Cretaceous.		Laramie Series, or Hadrosaurus Beds.	*Hadrosaurus, Dryptosaurus* (*Lælaps*).
			Fox Hill group.	
			Colorado Series, or Pteranodon Beds.	Birds with Teeth (*Odontornithes*), *Hesperornis, Ichthyornis.* Mosasaurs, *Edestosaurus, Lestosaurus, Tylosaurus.* Pterodactyls *Pteranodon*, Plesiosaurs.
			Dakota Group.	
	Jurassic.		Atlantosaurus Beds Baptanodon Beds.	Dinosaurs, *Atlantosaurus, Brontosaurus, Morosaurus, Diplodocus, Stegosaurus, Camptonotus, Allosaurus.* Turtles, *Diplosaurus.* Mammals *Dryolestes, Stylacodon, Tinodon, Ctenacodon.* Bird *Laopteryx. Baptanodon* (*Sauranodon*).
	Triassic.		Otozoum, or Conn. River, Beds.	First Mammals *Dromatherium.* Dinosaur Foot-prints, *Amphisaurus*, Crocodiles (*Belodon*).
Paleozoic.	Permian.		Nothodon Beds.	Reptiles *Nothodon, Sphenacodon.*
	Carboniferous		Coal Measures, or Eosaurus Beds.	First Reptiles (?) *Eosaurus.*
			Subcarboniferous, or Sauropus Beds.	First known Amphibians (Labyrinthodonts), *Sauropus.*
	Devonian.		Dinichthys Beds.	*Dinichthys.*
			Schoharie Grit.	First known Fishes.
	Silurian.		Upper Silurian.	
			Lower Silurian.	
	Cambrian.		Primordial.	No Vertebrates known.
	Archæan.		Huronian.	
			Laurentian.	

FIG. 37.—Section to illustrate vertebrate life in America.

mountain chains were elevated, the inclosed Cretaceous sea, cut off from the ocean, gradually freshened, and formed these extensive lakes, while the surrounding land was covered with a luxuriant tropical vegetation, and with many strange forms of animal life. As the upward movement of this region continued, these lake-basins, which for ages had been filling up, preserving in their sediments a faithful record of Eocene life-history, were slowly drained by the constant deepening of the outflowing rivers, and they have since remained essentially dry land.

The Miocene lake-basins are on the flanks of this region, where only land had been since the close of the Cretaceous. These basins contain three faunas, nearly or quite distinct. The lowest Miocene, which is found east of the Rocky Mountains, alone contains the peculiar mammals known as the *Brontotheridæ*, and these deposits have been called by the writer the Brontotherium beds. The strata next above, which represent the middle Miocene, have as their most characteristic fossil the genus *Oreodon*, and are known as the Oreodon beds. The upper Miocene, which occurs in Oregon, is of great thickness, and from one of its most important fossils, *Miohippus*, has been designated as the Miohippus series. The climate here during this period was warm temperate.

Above the Miocene, east of the Rocky Mountains, and on the Pacific coast, the Pliocene is well developed, and is rich in vertebrate remains. The strata rest unconformably on the Miocene, and there is a well-marked faunal change at this point, modern types now first making their appearance. For these reasons, we are justified in separating the Miocene from the Pliocene at this break; although in Europe, where no great break exists, the line seems to have been drawn at a somewhat higher horizon. Our Pliocene forms essentially a continuous series, although the upper beds may be distinguished from the lower by the presence of a true *Equus*, and some other existing genera. The Pliocene climate was similar to that of the Miocene. The Post-Pliocene beds contain many extinct mammals, and may thus be separated from recent deposits.[3]

With this introduction, the table of strata on page 253 will make clear the general position of the geological horizon in which the *Dinocerata* are found, and especially its relation to other deposits of Tertiary age. To make the subject clearer to the general reader, the section is enlarged to include the whole geological series. The names applied to the different horizons, some used here for the first time, are, in general, those of the most important vertebrates found in each, and the section thus becomes a condensed index of vertebrate life in America.

The localities in which the *Dinocerata* have been found are on both sides of the Green River, and mainly south of the Union Pacific Railroad,

[3] For a more complete presentation of this subject, see the author's address on the *Introduction and Succession of Vertebrate Life in America*, delivered before the American Association for the Advancement of Science, at Nashville, Tenn., August, 1877.

in Wyoming. Of two hundred individuals in the Yale Museum, about equal numbers were found east and west of this river, the distance between the extreme localities in this direction being more than 100 miles. The map on page 250 covers this region, and the more important localities are there indicated.

The remains of the *Dinocerata* are imbedded usually in indurated clays, gray or green in color, but sometimes they are found in hard sandstone. The series of strata inclosing them are at least five hundred feet in thickness in the same region, and all taken together are probably one thousand feet.

Among the fossils found associated with the *Dinocerata* are *Limnohyus* and *Palæosyops*, two genera of perissodactyl ungulates. They were somewhat larger than a tapir, and in these strata are next in size to the *Dinocerata*. One or the other of these genera occurs wherever the *Dinocerata* have yet been found, but the remains extend through a greater thickness of strata than those of the latter group. Another genus of ungulates in this horizon is *Orohippus*, a four-toed ancestor of the horse. Other prominent genera are *Colonoceras*, *Helaletes*, and *Hyrachyus*, related distantly to the tapir and rhinoceros.

Two genera, *Tillotherium* and *Stylinodon*, also found here, represent a remarkable order, named by the writer the *Tillodontia*. They were nearly as large as a tapir, and possessed characters resembling the Ungulates, the Carnivors, and the Rodents.

Among the Carnivors, the most formidable was *Limnofelis*, nearly as large as a lion, *Oreocyon*, of almost equal size, *Dromocyon*, somewhat smaller, and *Limnocyon*, about as large as a fox. Among the Lemuroid forms were *Hyopsodus* and *Lemuravus*, forming the family *Lemuravidæ*, and having some affinities with the South American Marmosets.

In addition to these, there were Marsupials, Insectivors, Chiroptera, and many Rodents, but apparently no true Quadrumana or Edentates.

Besides these mammals, there were numerous reptiles, especially crocodiles, turtles, lizards, and serpents, in great numbers. Fishes were also abundant, especially the genera *Amia* and *Lepidosteus*.

The *Dinocerata* form a well-marked order in the great group of *Ungulata*. In some of their characters they resemble the Artiodactyls (*Paraxonia*); in others, they are like the Perissodactyls (*Mesaxonia*); and in others still, they agree with the Proboscidians. The points of similarity, however, are in most cases general characters, which point back to an earlier, primitive, ungulate, rather than indicate a near affinity with existing forms of these groups.

The *Dinocerata*, so far as now definitely known, may be placed in three genera, *Dinoceras*, Marsh, *Tinoceras*, Marsh, and *Uintatherium*, Leidy. The type specimen of *Uintatherium* was discovered near the base of the series of strata containing the remains of the *Dinocerata*. *Dinoceras*, so far as known, occurs only at a higher horizon, while

Tinoceras has been found at the highest level of all. The characters of these three genera correspond in general with their geological position. *Uintatherium* appears to be the most primitive type, and *Tinoceras* the most specialized, *Dinoceras* being an intermediate form. The material at hand for determining the main characters of the two latter is abundant, but in regard to *Uintatherium*, some important points relating both to the skull and the skeleton still remain in doubt.

The number of species of the known *Dinocerata* is a difficult matter to determine, especially as the limitations between species are now generally regarded as uncertain. About twenty forms, more or less distinct, are recognized in the present article. The number might easily be increased, if fragmentary specimens were used as the basis for specific names.

THE SKULL.

The skull of *Dinoceras mirabile*, the type of the genus *Dinoceras*, on which the order *Dinocerata* was based, is, fortunately, the most perfect

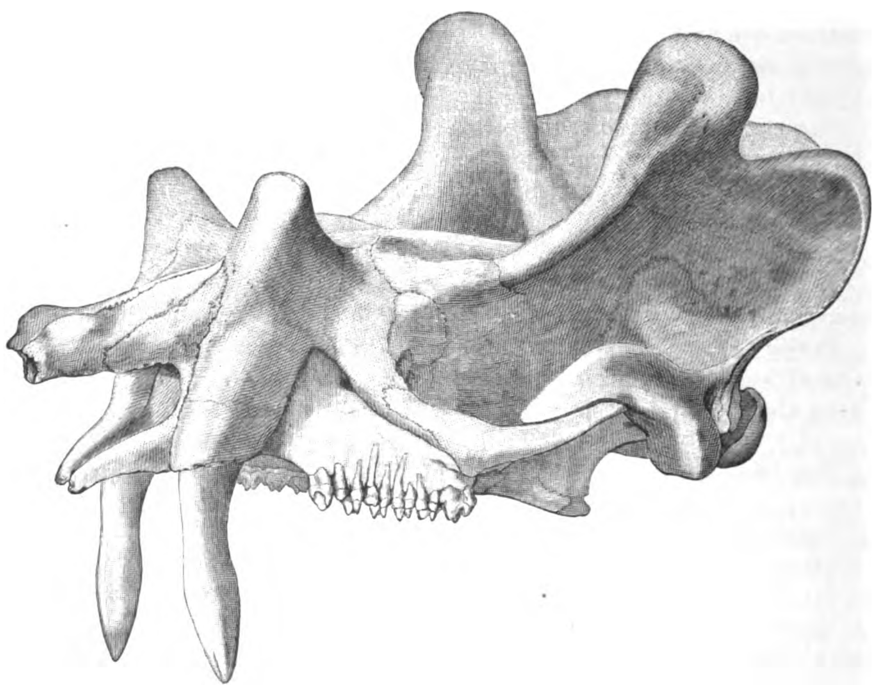


FIG. 38.—Skull of *Dinoceras mirabile*, Marsh, seen from the left; one-sixth natural size.

in preservation of any yet discovered in this group. It has in addition the great advantage for study of having belonged to an animal fully adult, but not so old as to have the more important sutures of the skull obliterated. It was, moreover, imbedded in so soft a matrix that the

brain-cavity and the foramina leading from it could be worked out without difficulty.

In its present nearly perfect condition, this skull is well adapted to show the typical characters of this part, both in the genus it represents and in the order *Dinocerata*, and it will be largely used for this purpose in the following pages. The fact that a considerable portion of the skeleton also was found with this skull makes the individual especially worthy to be a type.

The skull of *Dinoceras mirabile* is long and narrow, the facial portion being greatly produced. The basal line, extending from the end of the premaxillaries along the palate to the lower margin of the foramen magnum, is nearly straight. The top of the skull supports three, separate, transverse pairs of osseous elevations, or horn-cores, which form its most conspicuous feature, and suggested the name of the genus.

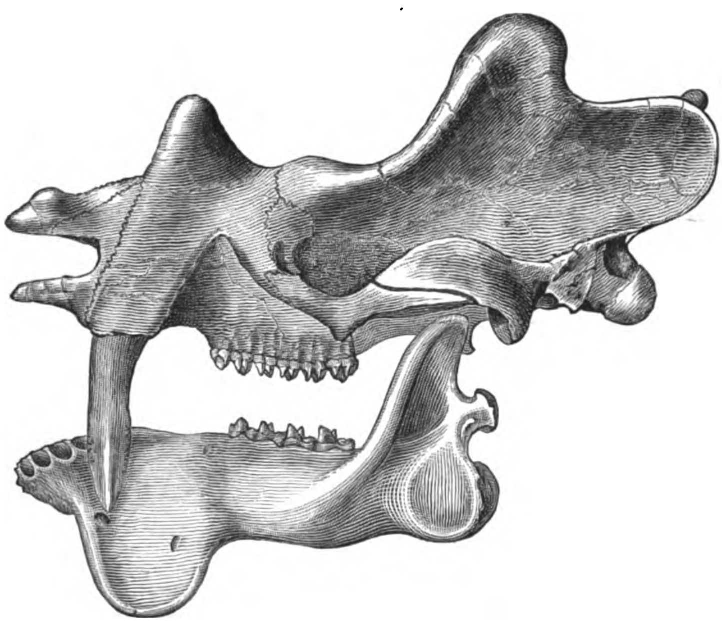


FIG. 39.—Skull and lower jaw of *Dinoceras mirabile*, Marsh, seen from the left; one-eighth natural size.

The smallest of these protuberances are situated near the extremity of the nasals; two others, much larger, arise from the maxillaries, in front of the orbits; while the largest are mainly on the parietals, and are supported by an enormous crest, which extends from near the orbits entirely around the lateral and posterior margins of the true cranium. These general characters are shown in Fig. 38, page 256, which represents the skull of the type specimen.

There are no upper incisors, but the canines in the male are enormously developed, forming sharp, trenchant, decurved tusks, which were each

protected by a dependent process on the lower jaws. The premolar and molar teeth are very small.

The orbit is large, and confluent with the temporal fossa. The latter is of great extent posteriorly, but the zygomatic arches are only moderately expanded. There is no post-orbital process, but in *Dinoceras mirabile*, and in some other species, there is a prominence on the frontal bone, directly over the orbit.

THE NASAL BONES.

The nasal bones are greatly elongated, being nearly half the length of the entire skull. They project forward over the anterior nares, and

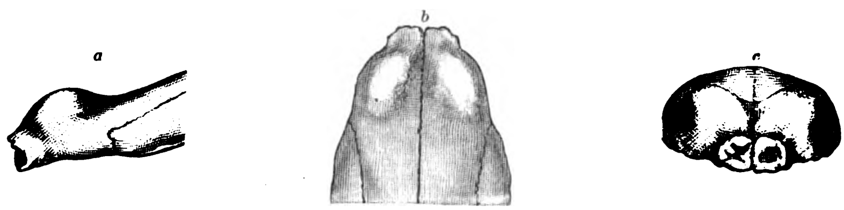


FIG. 40.—Nasals of *Dinoceras mirabile*, Marsh; type specimen.

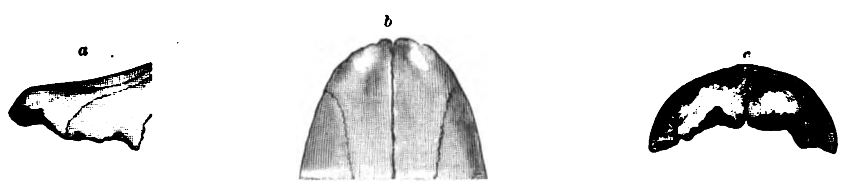


FIG. 41.—Nasals of *Dinoceras distans*, Marsh; young male.

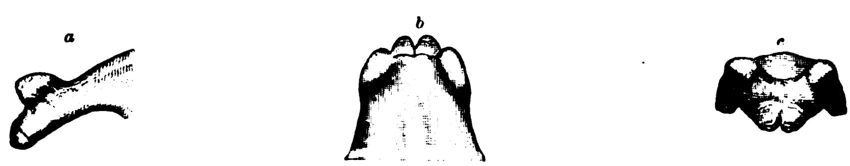


FIG. 42.—Nasals of *Tinoceras pugnax*, Marsh.

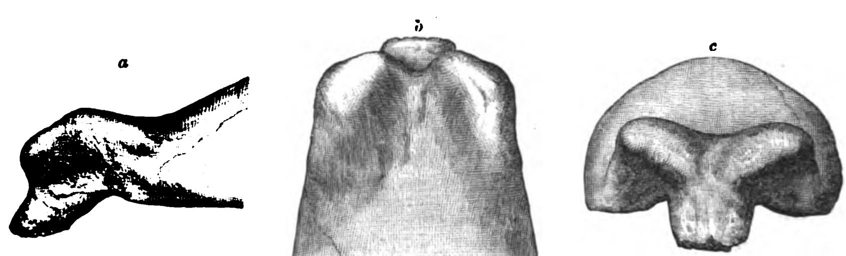


FIG. 43.—Nasals of *Tinoceras annectens*, Marsh. *a* side view; *b* top view; *c* front view. All the figures are one fifth natural size.

overhang the premaxillaries. They are thick and massive bones, especially in front, and are united together by a nearly straight suture.

In specimens not fully adult this suture remains an open fissure, and even in some adults it is not closed, especially in the anterior part.

The osseous prominences on the extremity of the nasal bones are their most marked feature. These vary much in form and size in the different genera of the group, and appear to be characteristic of the species. In *Dinoceras* they are small and sessile, and are directed upward, and somewhat outward; in *Tinoceras* they are larger, and, in most specimens, project more horizontally, usually not beyond the apex of the nasals. Some of the characteristic forms of these nasals are given above, Figs. 40–43, page 258.

On their lateral margins the nasal bones unite by suture with the superior branch of the premaxillary, and, behind this, with the maxillaries up to the point where they join the frontals. These lateral sutures disappear in the old animals, but are shown in the skull of *Dinoceras mirabile*, Figs. 38 and 39. Between the osseous protuberances, or horn-cores, of the maxillaries, the nasals thicken into a transverse ridge, which greatly strengthens the skull in this region. The development of this ridge varies in different species. The sutures between the nasals and maxillaries thus appears to rise on the inner face of each maxillary prominence, but the nasals do not form any essential part of these elevations. From this transverse ridge the nasals expand posteriorly, and meet the frontals by oblique sutures, converging behind to the median line. At the union with the frontals the nasal bones are comparatively thin.

On their under surface, the nasal bones are each excavated by a broad deep groove, which is separated from its fellow by a sharp median ridge. These grooves extend from the anterior nasal opening back to the frontal bones, and then expand into large cavities immediately in front of the olfactory lobes of the brain. These olfactory chambers differ in form and size in different species. This part of the skull is shown in the sections represented in Figs. 65–68.

PRE-NASAL BONES.

The anterior extremity of the nasal bones, in both *Dinoceras* and *Tinoceras*, is formed of an osseous projection, pointing forward and downward, and situated in front of and below the nasal protuberances. Several specimens in the Yale Museum show that this projection is formed of two separate ossifications, each in front of its respective nasal bone. In Fig. 42, they are shown in position, with the sutures uniting them to the nasals and to each other. These bones are a peculiar feature in the *Dinocerata*, and may be called the pre-nasal bones. In very young animals they are unossified; in adult animals they are distinct, as in the specimen figured; but in very old animals they become co-ossified with the nasals and with each other.

When separate, they are subquadrate in form, flattened on the median line where they meet each other, and rugose posteriorly, for sutural union with the nasals. These pre-nasal bones appear to be homologous with the ossicle sometimes found at the extremity of the snout in suillines, especially in the genus *Sus*.

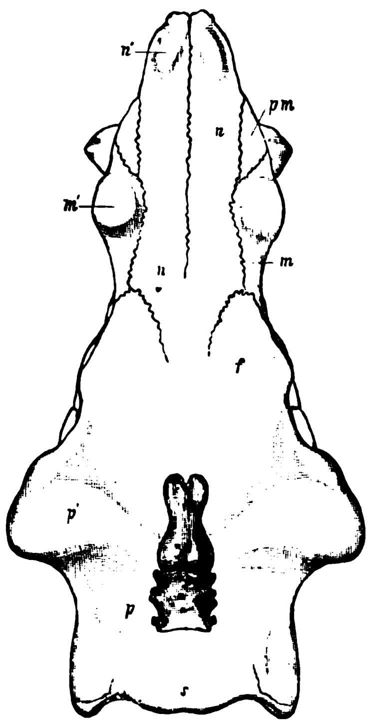


FIG. 44.—Skull of *Dinoceras mirabile*, Marsh, with brain-cast in natural position; seen from above.

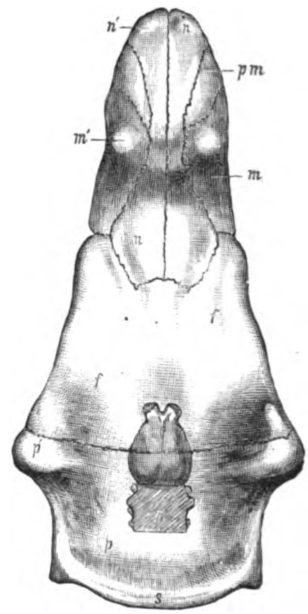


FIG. 45.—The same view of young specimen *Dinoceras distans*, Marsh. *f*, frontal bone; *m*, maxillary bone; *m'*, maxillary protuberance; *n*, nasal bone; *n'*, nasal protuberance; *p*, parietal bone; *p'*, parietal protuberance; *pm*, premaxillary bone; *s*, supraoccipital crest.

Both figures are one-eighth natural size.

FRONTAL BONES.

The frontal bones in *Dinoceras mirabile* are shorter than the nasals. In all of the known skulls of the *Dinocerata*, the median suture uniting the two frontals is entirely obliterated. The suture joining them with the nasals in front and with the maxillaries on the side is distinct in the type of *Dinoceras mirabile*, as shown in Fig. 44. In this specimen there appeared to be indications of a suture uniting the frontals with the parietals, which implied that the former bones were very short and the latter very long. The fortunate discovery, however, of a very young individual of this genus has cleared up this point beyond doubt.

In this young specimen the fronto-parietal suture is still open, and passes in a nearly straight line across the top of the cranium just in

front of the summit of the cerebral hemispheres. It also divides the posterior elevations, or horn-cores, so as to leave the anterior part of them on the frontals, and the posterior and highest portion on the parietals. In all the other known specimens this suture is nearly or quite obliterated, but distinct traces of it are seen in several crania in the Yale Museum.

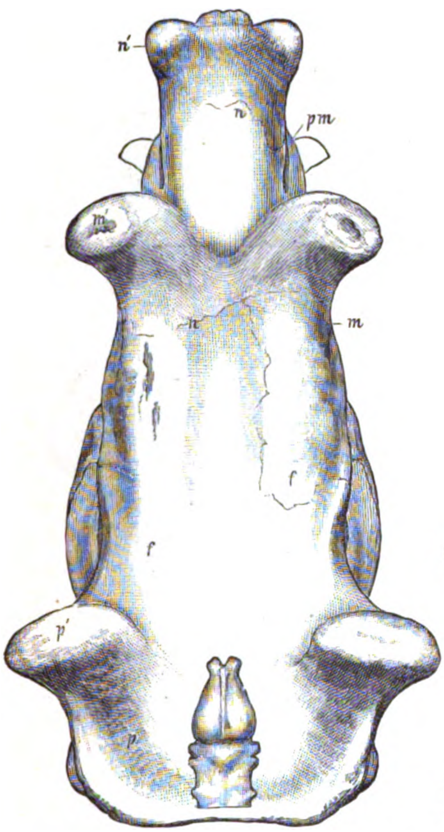


FIG. 46.—Skull of *Tinoceras ingens*, Marsh, with brain-cast in position; seen from above.

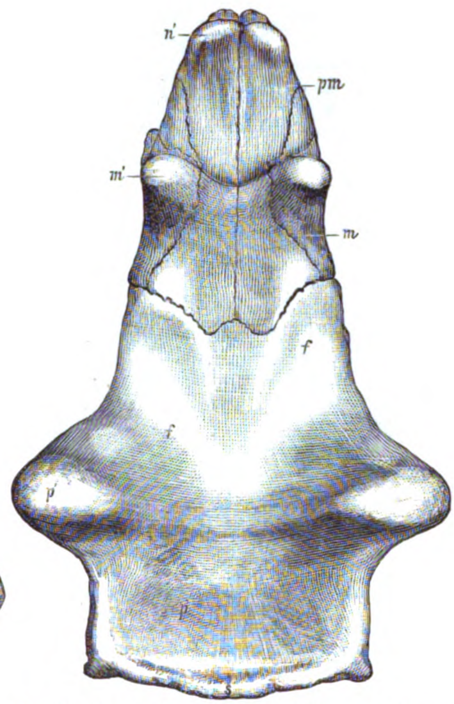


FIG. 47.—Same view of skull of *Dinoceras distans*, Marsh.
f, frontal bone; *m*, maxillary bone; *m'*, maxillary protuberance; *n*, nasal bone; *n'*, nasal protuberance; *p*, parietal bone; *p'* parietal protuberance; *pm*, premaxillary bone; *s*, supraoccipital crest.

Both figures are one-eighth natural size.

The position of this suture, and also that uniting the frontals with the nasals, and the latter with their adjoining bones, is well shown in Fig. 45, which represents the young specimen above referred to.

In *Dinoceras mirabile* the frontals are comparatively thin in front where they join the nasals. Over the orbits they become thicker, and swell into a distinct prominence, which afforded protection to the eye below. From this point back to the posterior protuberances, or horn-cores, the lateral margin of the frontal is thickened into a strong crest, which rises nearly to the summit of the elevations, leaving a distinct

notch where they terminate. This depression marks the position of the fronto-parietal suture, here entirely obliterated.

On the side of the cranium the frontal bones are bounded anteriorly by the maxillary above, and, lower down, by the lachrymal, as shown

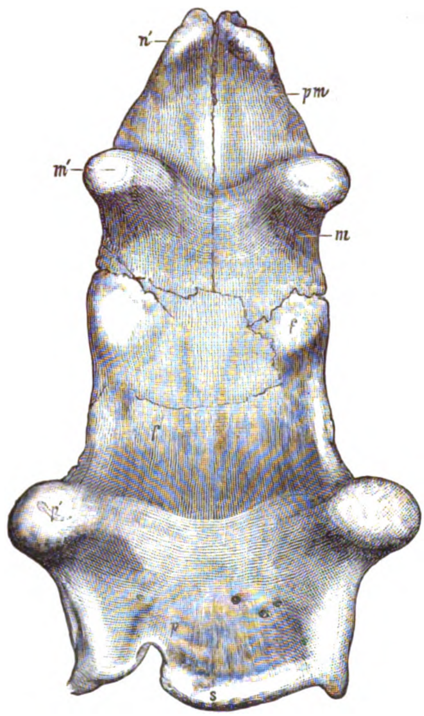


FIG. 48.—Skull of *Uintatherium latifrons*, Marsh, seen from above.

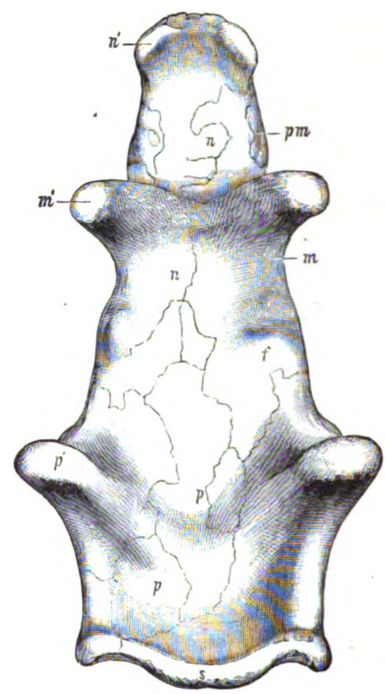


FIG. 49.—Same view of the skull of *Tinoceras vagans*, Marsh.

f, Frontal bone; *m*, maxillary bone; *m'*, maxillary protuberance; *n*, nasal bone; *n'*, nasal protuberance; *p*, parietal bone; *p'*, parietal protuberance; *pm*, premaxillary bone; *s*, supraoccipital crest.

Both figures are one-eighth natural size.

in Fig. 38, page 256. Further back on the top of the skull the frontals are depressed, forming a deep concavity, the lowest portion of which is directly over the brain-case. In the posterior portion of the frontals there are numerous air cells, which materially lighten these bones in this part of the cranium.

THE PARIETAL BONES.

In all of the crania of the *Dinocerata* examined the parietal bones are firmly united to each other on the median line, and with the supra-occipital behind. In the single young specimen already mentioned the anterior border of these bones is distinctly marked by sutures, as shown in Fig. 45, page 260. The large posterior protuberances, or horn-cores, are thus mainly on the parietal bones, and the lateral crest, behind these elevations, appears to be also composed of the parietals. These bones are thick and massive, especially over the brain-case, but like the frontals are lightened somewhat by air cavities, as shown in Fig. 70,

Between the osseous elevations, or horn-cores, on the parietals, there is a distinct transverse ridge, which strengthens this part of the cranium, and partially divides into two portions the deep concavity inclosed by the lateral and posterior crests. On the sides of the cranium the parietals form the upper portion of the large temporal fossæ. The suture between the parietal and squamosal below may often be distinctly made out, as shown in Figs. 38 and 39. The share of the parietals in the lofty occipital crest cannot, at present, be determined with certainty, as here, even in the youngest specimens known, the sutures are obliterated.

THE OCCIPUT.

The occipital region in all the known *Dinocerata* is large, elevated, and subquadrate in outline. It varies much in shape and size in the different genera and species, and some of the principal forms are represented below in Figs. 50–53.

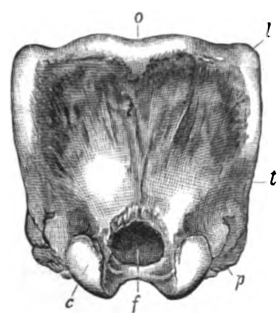


FIG. 50.—Posterior surface of skull of *Dinoceras mirabile*, Marsh.

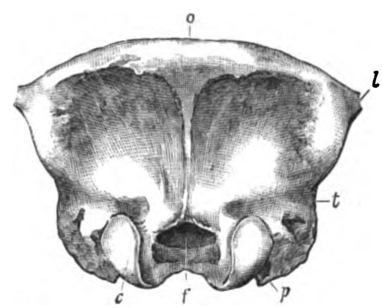


FIG. 51.—Posterior surface of the skull of *Dinoceras laticeps*, Marsh, male.

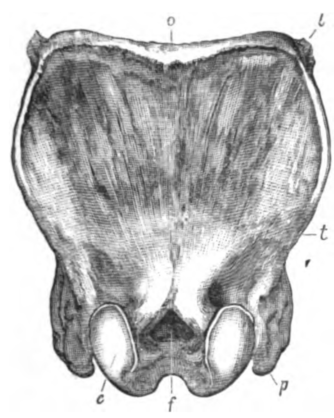


FIG. 52.—Posterior surface of skull of *Tinoceras ingens*, Marsh.

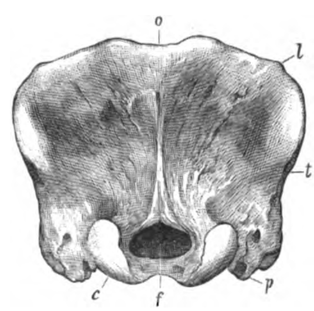


FIG. 53.—Posterior surface of skull of *Tinoceras pugnax*, Marsh.
_c_, occipital condyle; _f_, foramen magnum; _l_, lateral crest; _o_, occipital crest; _p_, post-tympanic process; _t_, crest behind temporal fossa.

All the figures are one-eighth natural size.

In *Dinoceras mirabile*, the occiput is remarkably rectangular in outline, as shown above in Fig. 50. Its general surface is concave, for

the attachment of the powerful muscles and ligaments which supported the head. The lofty occipital crest extends upward and backward, overhanging the occipital condyles, when the skull is in a horizontal

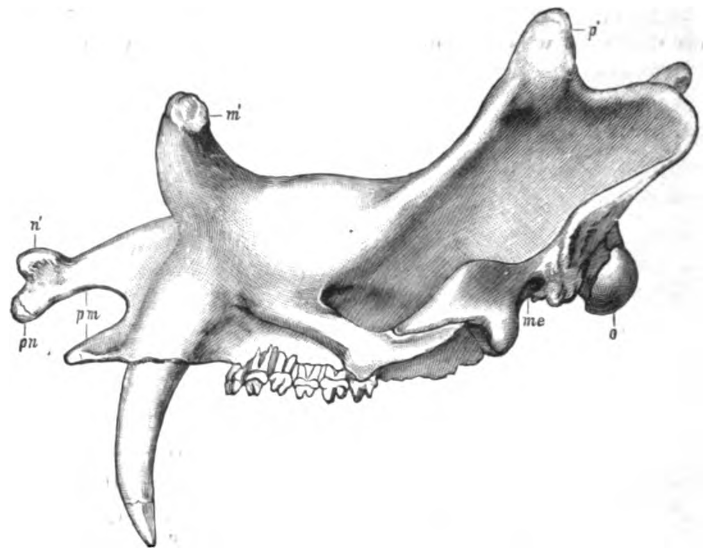
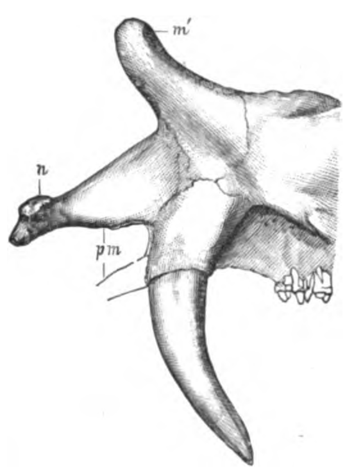


FIG. 54.—Side view of skull of *Tinoceras pugnax*, Marsh.



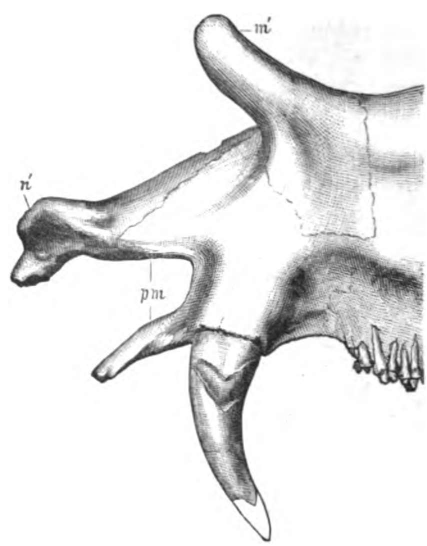


FIG. 55.—Anterior part of the skull of *Tinoceras grande*, Marsh.

FIG. 56.—Anterior part of the skull of *Tinoceras annectens*, Marsh.

m', maxillary protuberance; *me*, external auditory meatus; *n'*, nasal protuberance; *o*, occipital condyle; *p'*, parietal protuberance; *pm*, premaxillary bone; *pn*, prenasal ossicle.

All the figures are one-eighth natural size.

position. The posterior margin of the large temporal fossa also extends well backward, forming the side of the occipital concavity, which is partially divided into two equal portions by a median vertical ridge.

In some specimens this ridge is very distinct, but in others it is almost entirely wanting.

The occipital condyles are large, and bounded externally in front and below by a deep groove. They project downward and backward, showing that the head was declined when in its natural position.

In *Dinoceras laticeps*, the occiput is less elevated, and more expanded transversely, Fig. 51, page 263. Its concavity is divided into two portions by a distinct median vertical ridge. The foramen magnum also is expanded transversely, and is of moderate size. The occipital condyles are more elevated than in *Dinoceras mirabile*, a line joining their upper margins passing entirely above the foramen magnum.

In the genus *Tinoceras* two distinct types of occiput are represented in the Yale Museum. In *Tinoceras ingens* the occiput is greatly elevated, somewhat concave above, and expanded at the sides. There is no median crest. The foramen magnum is triangular in outline, and comparatively small, with its upper border lower than the superior margins of the occipital condyles, as seen in Fig. 52, page 263.

In *Tinoceras pugnax* the occiput is less elevated, and more nearly quadrate in outline. The foramen magnum is large, and transversely expanded. The occipital condyles extend above its upper margin, as shown in Fig. 53, page 263. In other species of the *Dinocerata* the occiput shows an equal variety of forms.

In *Dinoceras mirabile* there is a small, but distinct, par-occipital process of the exoccipital, directed downward and outward. In *Uintatherium* this process appears to be nearly or quite wanting. In front of this process is the suture uniting the exoccipital directly with the squamosal, thus excluding the mastoid from the external surface of the skull, as in Rhinoceros. The tympanic portion of the periotic also does not reach the external surface.

THE SQUAMOSAL BONES.

The squamosal forms the lower portion of the temporal fossa, and sends down a massive post-glenoid process, which bounds in front the external auditory meatus. The latter has for its posterior border the post-tympanic process of the squamosal, which unites directly with the par-occipital process by close suture.

The periotic and tympanic bones are co-ossified, but not with the squamosal. The periotic has a distinct floccular fossa on its inner side. The tympanic is small, and is not expanded into a distinct bulla.

The squamosal sends forward a strong zygomatic process, which resembles that in *Tapirus*. This process overlaps the malar, uniting to it by a straight, horizontal suture, which, in very old animals, may nearly or quite disappear.

THE MALAR BONES.

The malar bone completes the anterior portion of the zygomatic arch, extending to the front of the orbit, as shown in Figs. 38 and 39. The suture uniting the malar with the maxillary remains distinct till adult

life, and may usually be traced, even in old animals. This forward extension of the malar bone is a Perissodactyl character, also, and quite different from what is seen in the Proboscidians, where the malar forms the middle portion only of the zygomatic arch.

THE LACHRYMAL BONES.

The lachrymal is large, and forms the anterior border of the orbit, as shown in Fig. 38, page 256. It is perforated by a large foramen. In *Dinoceras mirabile* this is oval in outline, with the apex above. The base of the lachrymal is excavated for the posterior opening of the large antorbital foramen.

THE MAXILLARIES.

In all the *Dinocerata* the maxillary bones form a large portion of the lateral surface of the skull. They contain all the teeth, except those of the lower jaw, and also expand into the large median pair of osseous elevations, or horn-cores. On the external lateral surface, the maxillaries unite above with the frontals by suture; below this with the lachrymals, and further down with the malar. This is shown in the figure of *Dinoceras mirabile*, page 256. In front the maxillaries unite with the premaxillaries by a nearly straight and nearly vertical suture. Above they join the nasals, as already described.

The large canine tusk is entirely enclosed in the maxillary, and in the genus *Dinoceras* its root extends upward into the base of the maxillary elevation. In all known *Dinocerata* there is a diastema between the upper canine and the premolars. The latter are small, and form with the molars a continuous series. On their inner surface the maxillaries send in strong palatine plates which meet on the median line. The maxillary is perforated by a large antorbital foramen, the outlet of which is concealed, in the side view of the skull by a ridge extending upward in front of the orbit. Its position is shown in Figs. 57–59, *c*, page 267.

THE PREMAXILLARIES.

The premaxillary bones are edentulous, and, even in young specimens, contain no teeth. These bones have three distinct branches, the largest of which extends well forward below the anterior nasal opening. The second branch also extends forward above this opening, forming with the nasal its superior border, as shown in the type of *Dinoceras mirabile*, Fig. 38. The third branch is a horizontal plate extending inward to the median line, where it joins its fellow, and thus completes the anterior portion of the palate.

The anterior free portions of the premaxillaries are well separated on their palatal surface, but these bones meet somewhat in front of the anterior palatine foramina.

The premaxillaries vary much in form in the different genera and species of *Dinocerata*. Two of the principal forms in the genus *Dinoceras* are shown in Figs. 61 and 62, page 268, and two of the genus *Tinoceras* in Figs. 58 and 59, on page 267.

THE PALATE.

In all the *Dinocerata* the palate is very narrow and much excavated, especially in front. The palatine surface of the maxillaries extends from the anterior border of the large canine teeth to behind the molars.

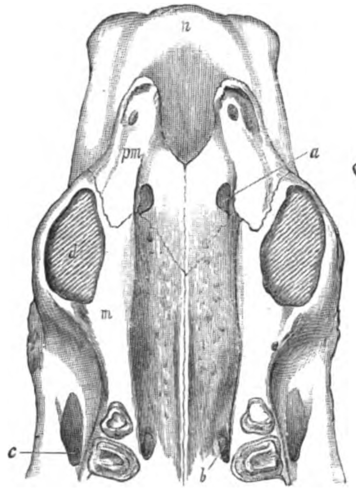


FIG. 57.—Anterior part of the palate of *Dinoceras laticeps*, Marsh.

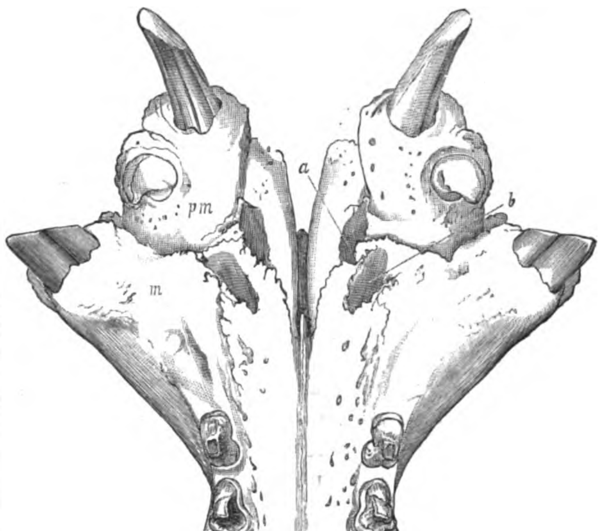


FIG. 60.—Anterior part of palate of *Hippopotamus amphibius*, Linn.

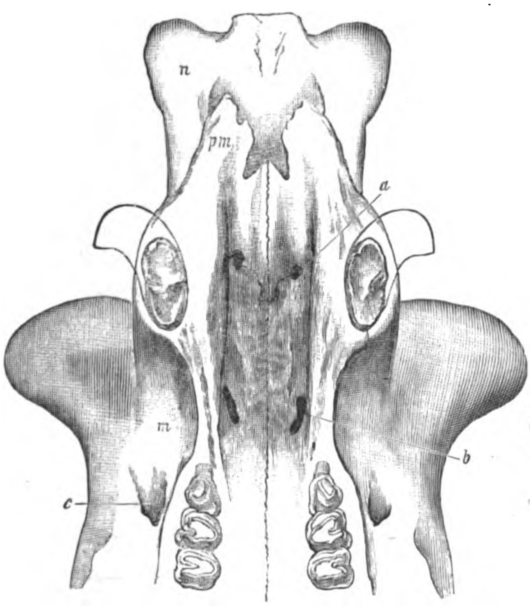


FIG. 58.—Anterior part of palate of *Tinoceras ingens*, Marsh.

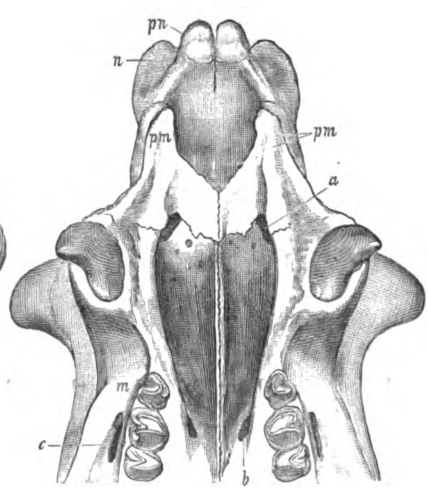


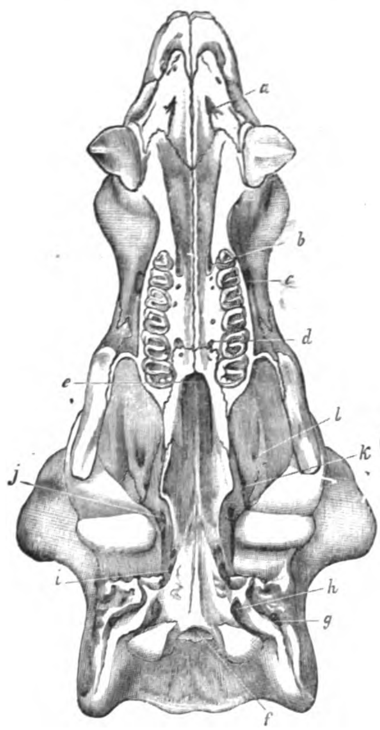
FIG. 59.—Anterior part of palate of *Tinoceras pugnax*, Marsh.

a, Anterior palatine foramen; *b* palato-maxillary foramen; *c*, antorbital foramen; *d*, socket of canine; *m*, maxillary bones; *n*, nasal bones; *pm*, premaxillary bones; *pn*, prenasal ossicles.

All the figures are one-fifth natural size.

The palatal surface of each maxillary is deeply excavated in front between the canines, along the diastema, and as far back as the second or third molar; but on the median line these bones meet in a sharp ridge nearly on a level with the outer opposite border of the maxillaries.

The bony palate is thus deeply excavated on each side in the region of the diastema, and near the posterior part of each excavation on either side is situated a large foramen, which may be called the palato-maxillary foramen. This foramen is shown in Figs. 57–59, *b*, page 267. The same foramen is seen also in the hippopotamus.



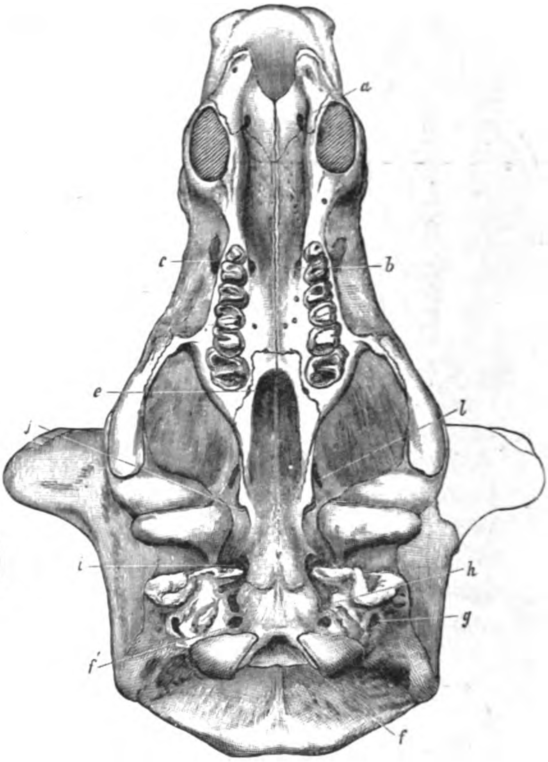


FIG. 61.—Skull of *Dinoceras mirabile*, Marsh, seen from below.

FIG. 62.—Skull of *Dinoceras laticeps*, Marsh, same view.

a, Anterior palatine foramen; *b*, palato-maxillary foramen; *c*, antorbital foramen; *d*. posterior palatine foramen; *e*, posterior nares; *f*, foramen magnum; *f′*, occipital foramen; *g*, stylo-mastoid foramen; *h*, foramen lacerum posterius; *i*, vascular foramen in basisphenoid; *j*, posterior opening of alisphenoid canal; *k*, anterior opening of alisphenoid canal; *l*, optic foramen.

Both figures are one-eighth natural size.

The palatine surface of the maxillary bone is perforated with small foramina, as in the hippopotamus, along the line of the inclosed canal, evidently for the transmission of blood-vessels and nerves to the gums and surface of the palate.

The maxillary bones contain the sockets of all the upper teeth. The socket for the canine is a large and deep cavity, elongate-oval in section,

and extending upward and backward to the posterior part of the base of the large maxillary protuberance. The outer surface of the maxillary bone is swollen by this socket, so as to present, in the males at least, a prominent rounded ridge on the side of the face. The alveoli for the premolar and molar series of teeth are similar to each other, each presenting three pits for the reception of roots, viz, an inner large pit, and two outer small ones. Over these, the bone is thin, as is usual on the buccal surface of the maxillary.

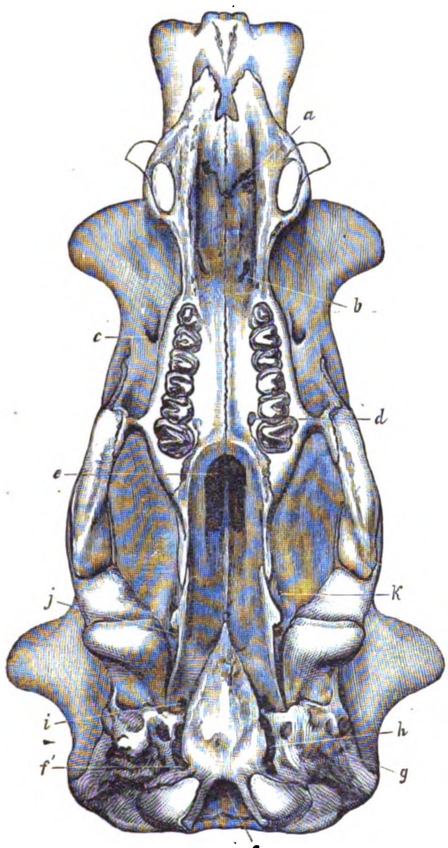


FIG. 63.—Skull of *Tinoceras ingens*, Marsh, seen from below.

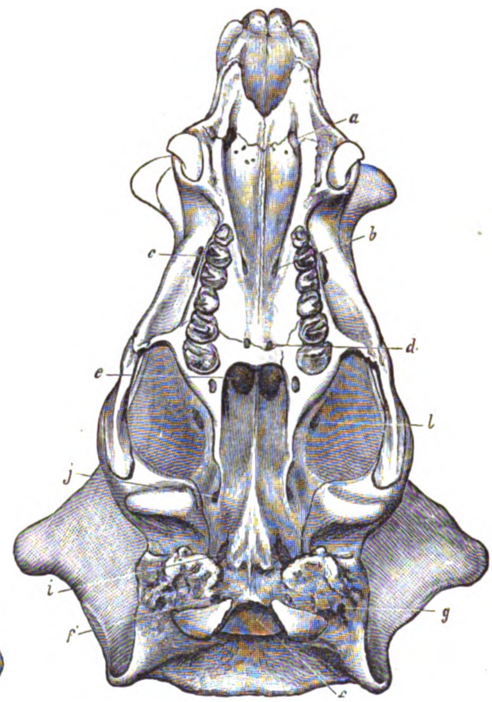


FIG. 64.—Skull of *Tinoceras pugnax*, Marsh; same view; *a*, anterior palatine foramen; *b*, palato-maxillary foramen; *c*, antorbital foramen; *d*, posterior palatine foramen; *e*, posterior nares; *f*, foramen magnum; *f'*, occipital foramen; *g*, stylo-mastoid foramen; *h*, foramen lacerum; *i*, vascular foramen in basisphenoid; *j*, posterior opening of alisphenoid canal; *k*, anterior opening of alisphenoid canal; *l*, optic foramen.

Both figures are one-eighth natural size.

THE PALATINE BONES.

The palatine bones form only a small part of the bony palate in *Dinoceras*. The palato-maxillary suture in *Dinoceras mirabile* is nearly opposite the middle of the second molar. It is at first nearly transverse to the palate, then runs backward around the last molar, and turns upward into the orbital region, where it cannot be followed with

certainty. Posteriorly, the palatine is in contact with the pterygoid, and the pterygoid plate of the alisphenoid. On the median line of the palate, the suture between the opposite palatines is obliterated.

The palatines continue the lateral walls of the posterior nasal cavities considerably behind the last molar, and these walls are still further extended by the pterygoid bones.

THE PTERYGOID BONES.

The pterygoid bones in *Dinoceras mirabile* are applied to the inner surface of the palatines, and to the pterygoid plates of the alisphenoid. They appear to unite on the median line in the roof of the posterior nares, but the suture is not distinct. The suture with the palatine is

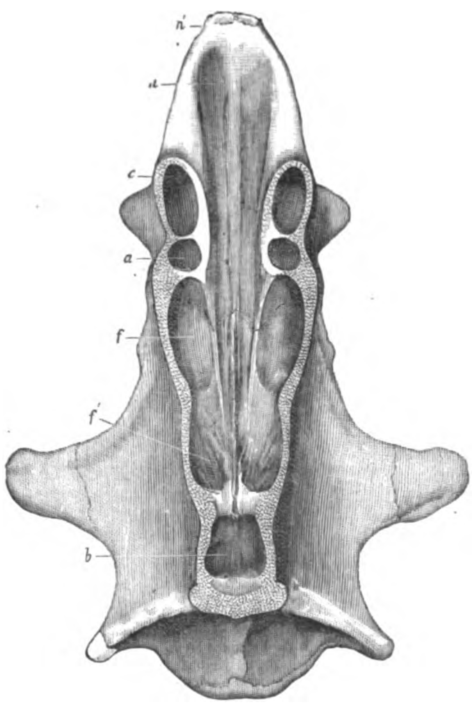


Fig. 65.—Horizontal section of skull of *Tinoceras crassifrons*, Marsh.

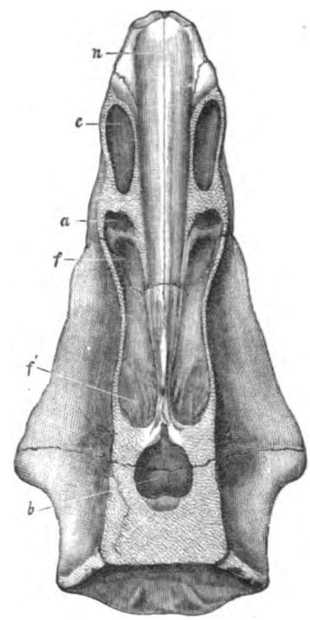


Fig. 66.—Horizontal section of skull of *Dinoceras distans*, Marsh; *a*, cavity behind base of canine tooth; *b*, brain cavity; *c*, socket of canine tooth; *f*, anterior olfactory chamber; *f'*, posterior olfactory chamber; *m'*, maxillary protuberance; *n*, nasal bones; *n'*, nasal protuberance; *p'*, parietal protuberances.

Both figures are one-eighth natural size.

oblique, and that with the alisphenoid can be traced upward beneath the zygomatic arch.

In the skull of *Tinoceras ingens* the palate is only slightly excavated in its anterior part, and the palato-maxillary foramina are brought forward in front of the entire series of molar teeth, instead of being situated nearly opposite the second premolar. The palate between the

whole series of molar teeth is nearly flat. The foramen in the maxillo-palatine suture behind the last molar is large and conspicuous, especially on the left side. These foramina are shown in Fig. 63, page 269.

In the type of *Tinoceras grande*, the maxillo palatine foramen is behind the beginning of the molar series, and the excavation of the palatal region also extends behind the first premolars.

In the genus *Dinoceras*, the palatine fossa of the posterior nares is roofed over, so that the passage from the palate into the large nasal cavities above leads forward, as shown in Fig. 61, *e*, page 268.

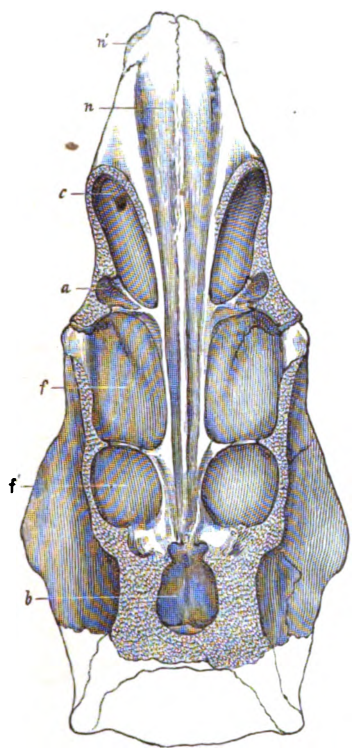


Fig. 67.—Horizontal section of skull of *Tinoceras hians*, Marsh.

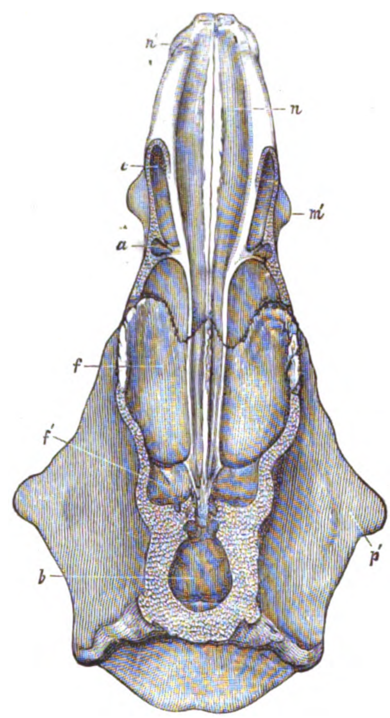


Fig. 68.—Horizontal section of skull of *Dinoceras laticeps*, Marsh, female. *a*, cavity behind base of canine tooth; *b*, brain-cavity; *c*, socket of canine tooth; *f*, anterior olfactory chamber; *f'*, posterior olfactory chamber; *m'*, maxillary protuberance; *n*, nasal bones; *n'*, nasal protuberances; *p'*, parietal protuberances.

Both figures are one-eighth natural size.

In *Tinoceras*, the roof of this fossa is excavated by a pair of large oval apertures, and through these the posterior nares open directly upward, as represented in Figs. 63 and 64, *e*, on page 269. The existing perissodactyls, the horse, the tapir, and rhinoceros, have the same type of palate. In *Uintatherium*, the structure of this portion of the skull has not yet been determined with certainty.

These palatine characters of the *Dinocerata* are important, but unfortunately they can be made out only in skulls unusually well preserved.

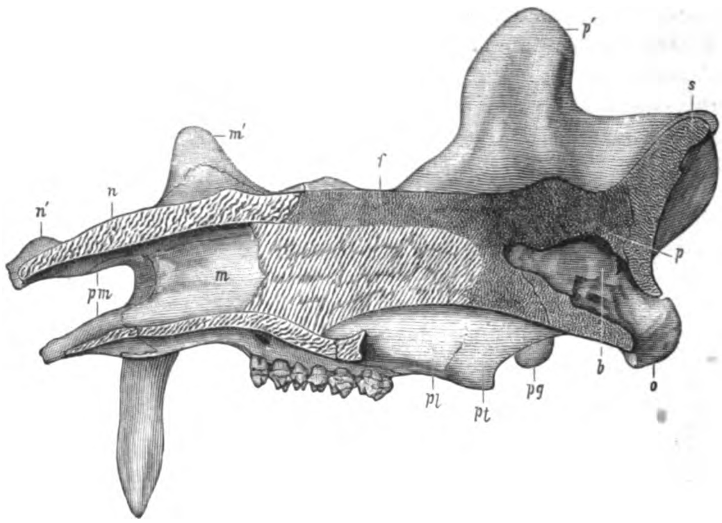


FIG. 69.—Vertical longitudinal section of skull of *Dinoceras mirabile*, Marsh.

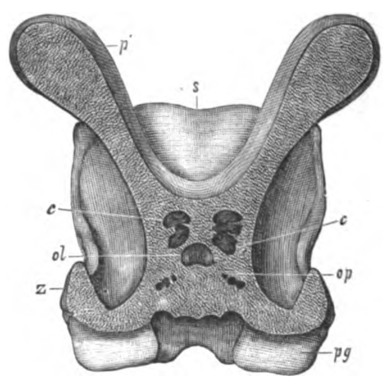


FIG. 70.—Vertical transverse section of skull of *Dinoceras mirabile*.

b, brain-cavity; *c*, cavities in cranial walls; *f*, frontal bone; *m*, maxillary bone; *m'*, maxillary protuberance; *n*, nasal bone; *n'*, nasal protuberance; *o*, occipital condyle; *ol*, olfactory lobes of brain; *op*, optic foramen; *p*, parietal bone; *p'*, parietal protuberance; *pg*, post-glenoid process; *pl*, palatine bone; *pm*. premaxillary bone; *pt*, pterygoid bone; *s*, supra-occipital crest; *z*, zygomatic process of squamosal.

Both figures are one-eighth natural size.

THE VOMERS.

The vomers in the *Dinocerata* do not appear upon the surface of the palate. They are narrow bones, closely united, and deeply concave upon their upper surface. They are wedged in between the palatine plates of the maxillaries, and in adult animals are closely united with them.

The groove formed by the upper concave surfaces of the vomers is filled by the turbinal bones, which are well developed.

THE LOWER JAW.

The lower jaw in *Dinoceras* is as remarkable as the skull. Its most peculiar feature in the male is a massive decurved process on each ramus,

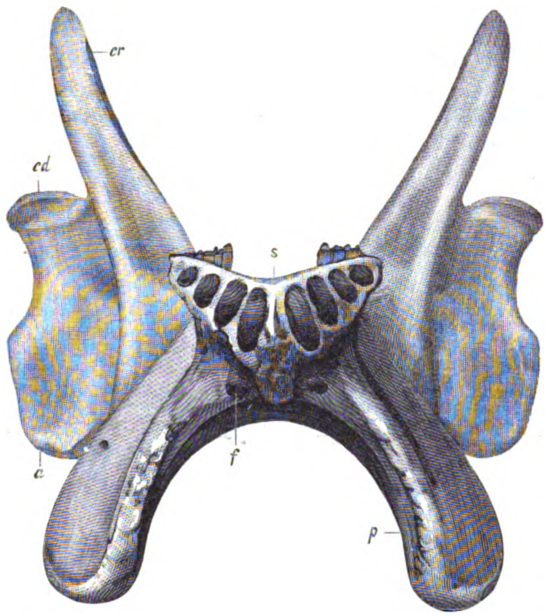


FIG. 71.—Lower jaw of *Dinoceras laticeps*, Marsh Front view.

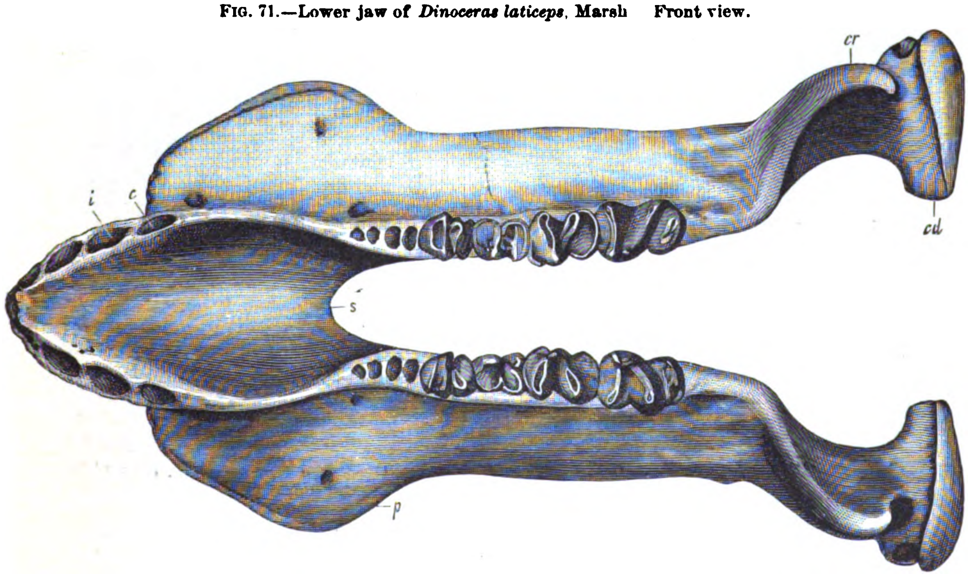


FIG. 72.—The same, seen from above; *a*, angle; *c*, alveole of canine; *cr*, coronoid process; *cd*, condyle; *f*, anterior foramen; *i*, alveole of incisor; *p*, process for protection of tusk; *s*, symphysis.
Both figures are one-fourth natural size.

extending downward and outward. These long pendent processes were apparently to protect the upper canine tusks, which would otherwise be very liable to be broken. Indications of similar processes are seen in *Smilodon*, and in some other extinct carnivors with long canines.

In the female this process is much reduced in size, but is quite sufficient to protect the diminutive tusk, which overlaps it.

With the exception of these processes, the lower jaw is comparatively small and slender. The symphysis is completely ossified and deeply excavated above.

Another remarkable feature in the lower jaw of the *Dinocerata* is the posterior direction of the condyles, hitherto unknown in Ungulates.

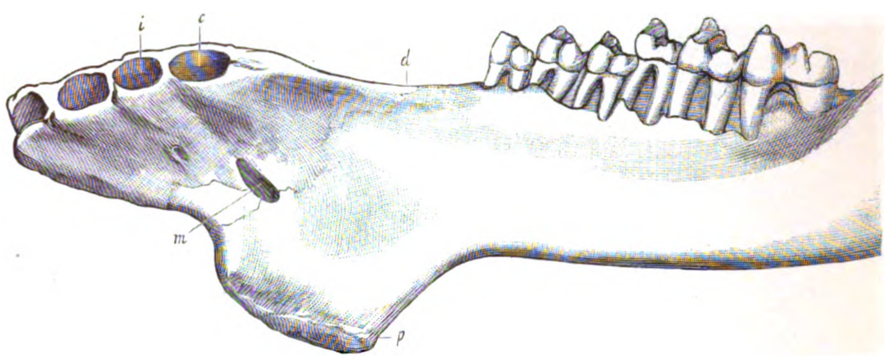


FIG. 73.—Lower jaw of *Tinoceras annectens*, Marsh. Seen from the left.

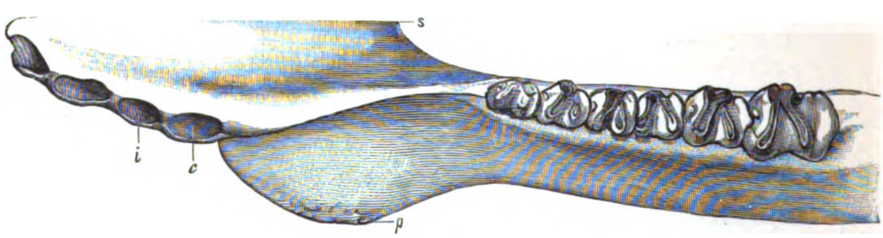


FIG. 74.—The same, seen from above. *c*, alveole of lower canine; *d*, diastema; *i*, alveole of incisor; *m*, mental foramen; *p*, process for protection of canine tusk; *s*, symphysis.
Both figures are one-fourth natural size.

The position of the condyles was evidently necessitated by the long upper tusks, since with the ordinary ungulate articulation the mouth could not have been fully opened. The low position of the condyle, but little above the line of the teeth, is also a noteworthy character. In some Marsupials and Insectivors the condyle has the same position as in the *Dinocerata*, but in no other Ungulates, living or extinct, has this position been observed.

The coronoid process of the lower jaw in *Dinoceras* is large and elevated, somewhat curved backward, and pointed above. The angle of the jaw is rounded in outline, and projects downward somewhat below the main portion of the ramus.

In the genus *Tinoceras*, the same general characters of the lower jaws are seen. In the male, the pendent process is large and elongate, but less massive than in the genus *Dinoceras*, and its lower outline less reg-

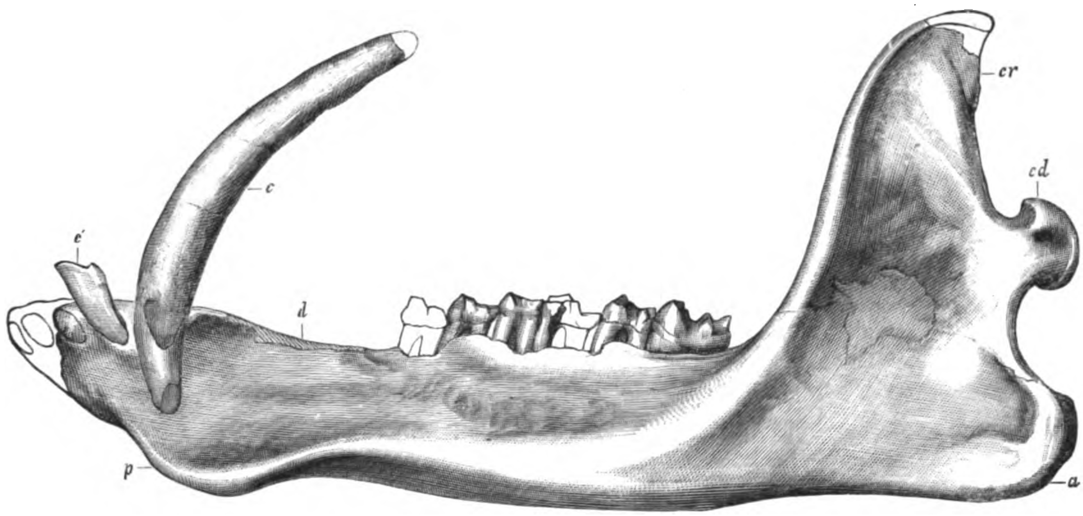
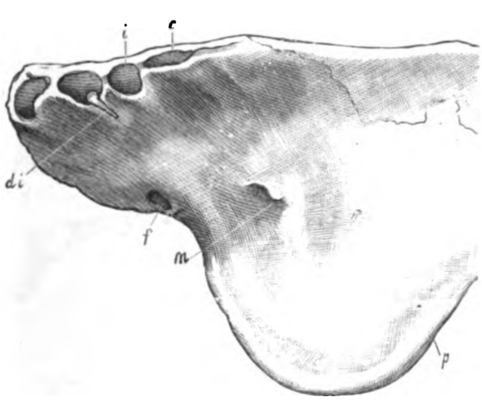


FIG. 75.—Lower jaw with upper canine in position of *Tinoceras longiceps*, Marsh, female; seen from the left. *a*, angle of jaw; *c*, upper canine tooth in its natural position; *c'*, lower canine tooth; *cd*, condyle; *cr*, coronoid process; *d*, diastema; *p*, process for protection of canine tusk. One-fourth natural size.

ularly rounded. This corresponds with the position of the large upper canine tusk, which it protects.

In the female of *Tinoceras*, the pendent process is much reduced, its size in all cases corresponding to the size of the canine tusk above. In



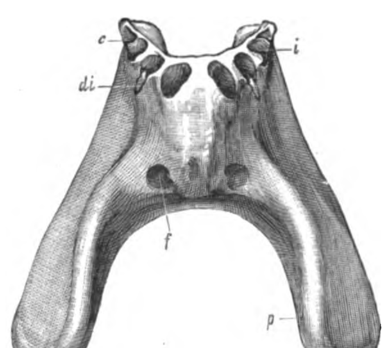


FIG. 76. -Lower jaw of *Dinoceras mirabile*, Marsh, seen from the left.

FIG. 77.—The same, seen from the front. *c*, canine; *f*, foramen; *di*, deciduous incisor; *i*, alveole of incisor; *m*, mental foramen; *p* process for protection of tusk.

Both figures are one-fourth natural size.

the female of *Tinoceras longiceps* (Fig. 75, above), the lower jaw is remarkably long and slender, and the pendent process nearly obsolete.

That the same relation in size between the tusk and process below it holds equally in both the genera *Dinoceras* and *Tinoceras*, is conclusively shown by various specimens in the Yale Museum.

In the genus *Dinoceras* there are three incisor teeth, and a small incisform canine on each side forming a continuous series at the front extremity of the lower jaw. These are all of moderate size, and inclined well forward, as in the ruminant mammals. Behind this series, and

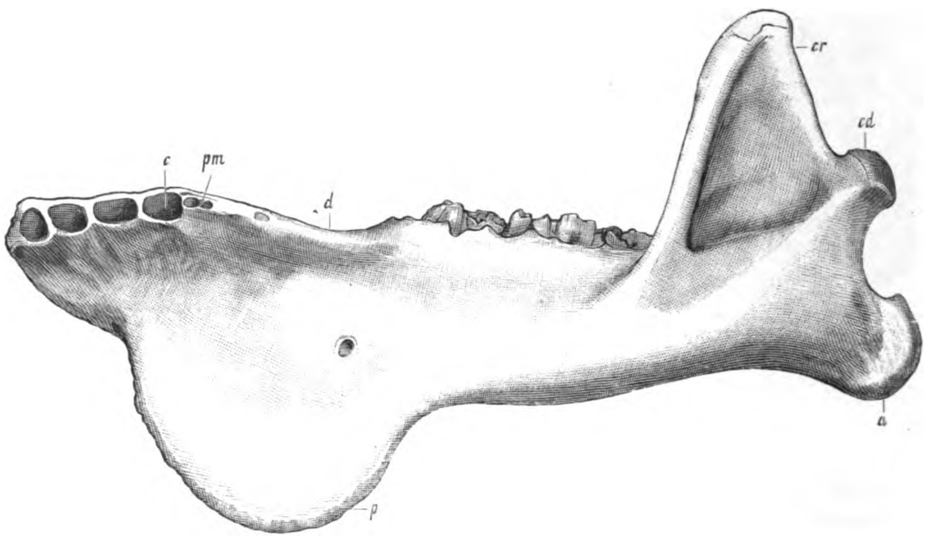


FIG. 78.—Lower jaw of *Uintatherium segne*, Marsh, seen from the left.

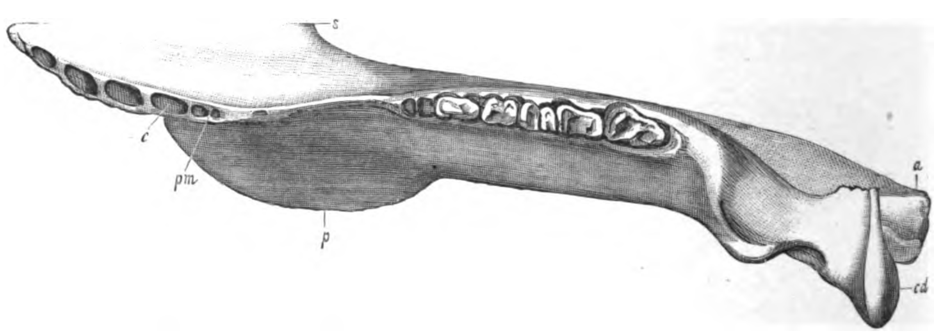


FIG. 79.—The same, seen from above. *a*, angle; *c*, alveole of canine; *cr*, coronoid process; *cd*, condyle; *d*, diastema; *p*, process for protection of tusk; *pm*, alveole of premolar. Both figures are one-fourth natural size.

immediately over the dependent process, is a long diastema. Further back there are three premolars and three molars, forming together a close series. This is the dentition, essentially, in the lower jaw of both *Dinoceras* and *Tinoceras*.

In a lower jaw found near the locality of the type of *Uintatherium robustum*, and here referred to that genus, there are four premolars instead of three. The first premolar, wanting in *Dinoceras* and *Tinoceras*, is of small size, and is placed just behind the lower canine. It is separated from the second premolar by a diastema as shown in figures 78 and 79.

In the present state of knowledge of the *Dinocerata*, this first lower premolar may be regarded as a distinctive feature of the genus *Uintatherium*, the type specimen of which, unfortunately, is too fragmentary for a complete determination of its principal characters.

THE TEETH.

The teeth of the *Dinocerata* constitute one of their most interesting features, differing widely from those of any of the other *Ungulata*.

In the genus *Dinoceras* the dentition is represented by the following formula:

$$\text{Incisors } \frac{0}{3}, \text{ canines } \frac{1}{1}, \text{ premolars } \frac{3}{3}, \text{ molars } \frac{3}{3} = 34.$$

So far as known the same formula applies equally well to the genus *Tinoceras*.

In *Uintatherium* the dentition is apparently as follows:

$$\text{Incisors } \frac{0}{3}, \text{ canines } \frac{1}{1}, \text{ premolars } \frac{3}{4}, \text{ molars } \frac{3}{3} = 36.$$

THE INCISORS.

In none of the *Dinocerata* have any upper incisors been found, even in the youngest specimens. The premaxillary bones appear to be entirely edentulous, although in some specimens, especially in *Dinoceras laticeps*, there are shallow depressions at irregular intervals that strongly suggest the probability of embryonic teeth in very young, or fœtal individuals. A fortunate discovery in the future may, perhaps, settle this point.

In the lower jaws of all the known *Dinocerata* there are three well-developed incisors on each side. They are inserted each by a root, and are procumbent, all directed well forward. Their inner surfaces continue the deep groove on the part of the lower jaw above the symphysis. The position of the sockets for these teeth in *Dinoceras* is shown in figures 71 and 72, page 273.

The crowns of these incisors are covered with enamel, and the special features of both crown and root are shown in Figs. 80 and 82.

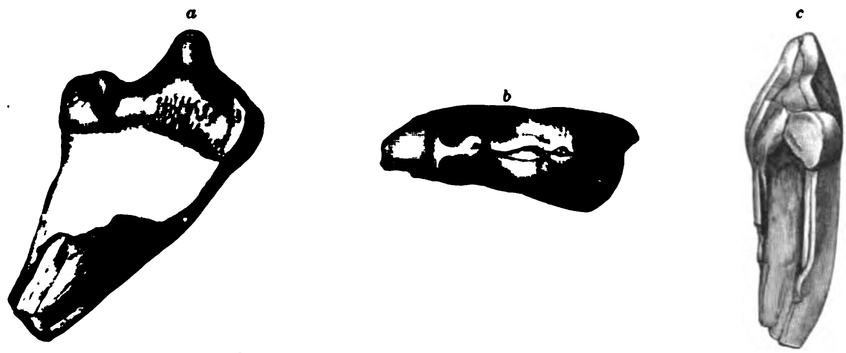


Fig. 80.—Incisor of *Dinoceras mirabile*, Marsh

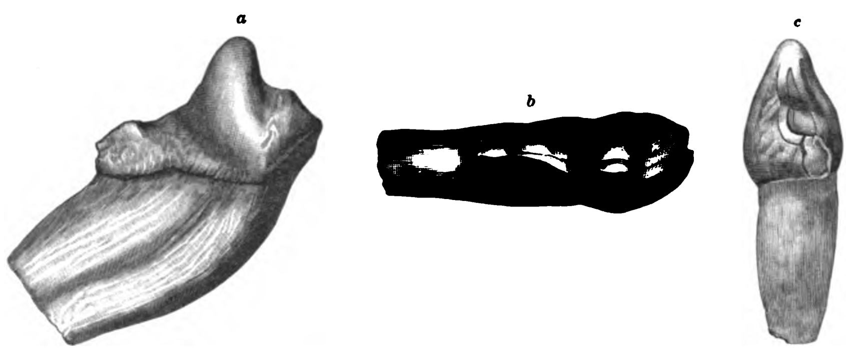


Fig. 81.—Incisor of *Dinoceras mirabile*.

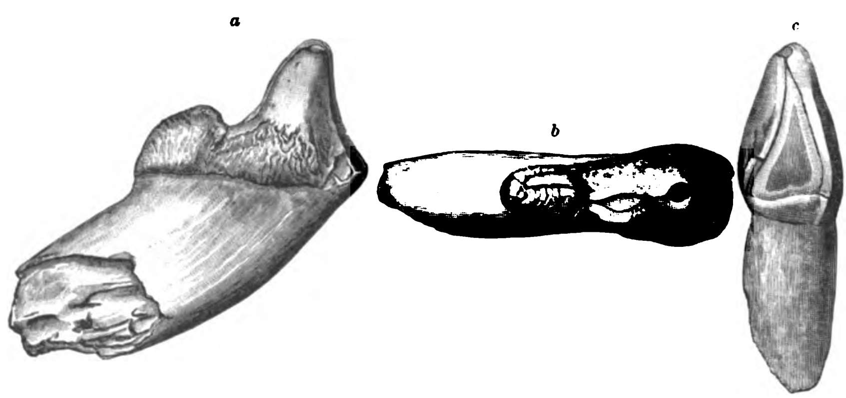


Fig. 82.—Incisor of *Dinoceras mirabile*. *a*, side view; *b*, top view; *c*, antero-posterior view. All the figures are of natural size.

In the genus *Tinoceras*, the incisors are similar in form, but have a less inclined position, as indicated in Figs. 73 and 75, pages 274 and 275.

THE CANINES.

The superior canines of *Dinoceras* are long, decurved, trenchant tusks. The crown is covered with enamel, and the root extends upward into the base of the maxillary protuberance, or horn-core. When the

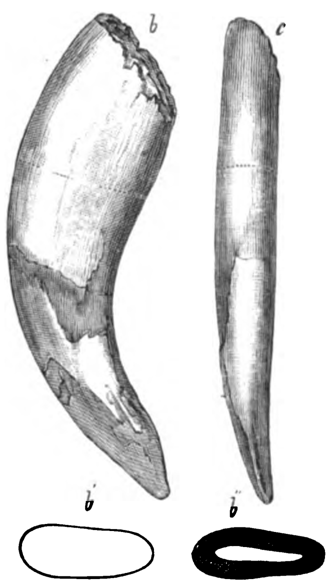


FIG. 83.—Upper canine of *Dinoceras lucare*, Marsh; male. *b*, lateral view inner surface; *b'*, outline of section of tooth; *b''*, section of tooth showing pulp cavity; *c*, front view of tooth.

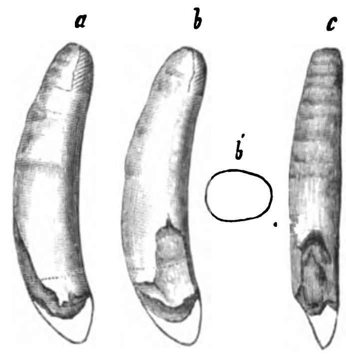


FIG. 84.—Upper canine of *Dinoceras laticeps*, Marsh; female.

FIG. 85.—Upper canine of *Tinoceras longiceps*, Marsh; female.
a, outer surface; *b*, inner surface; *b'*, outline of section; *c*, front view. The dotted line on the teeth marks the position of the alveolar border, below which the tusk was exposed.

All the figures are one-fourth natural size.

animal is young these tusks grow from a persistent pulp, but in old age the cavity becomes nearly closed. In the male these tusks are large and powerful, and extend downward nearly or quite to the extremity of the pendent process of the lower jaw.

In *Dinoceras mirabile* the canine tusks are oval in section, where they emerge from the jaw, then become somewhat constricted, before expanding into a wide, thin, lanceolate extremity, as shown in Fig. 38, page 256. On the outer surface of these tusks there is a distinct ridge in the lower half exposed, giving there a subtriangular or bayonet-like form.

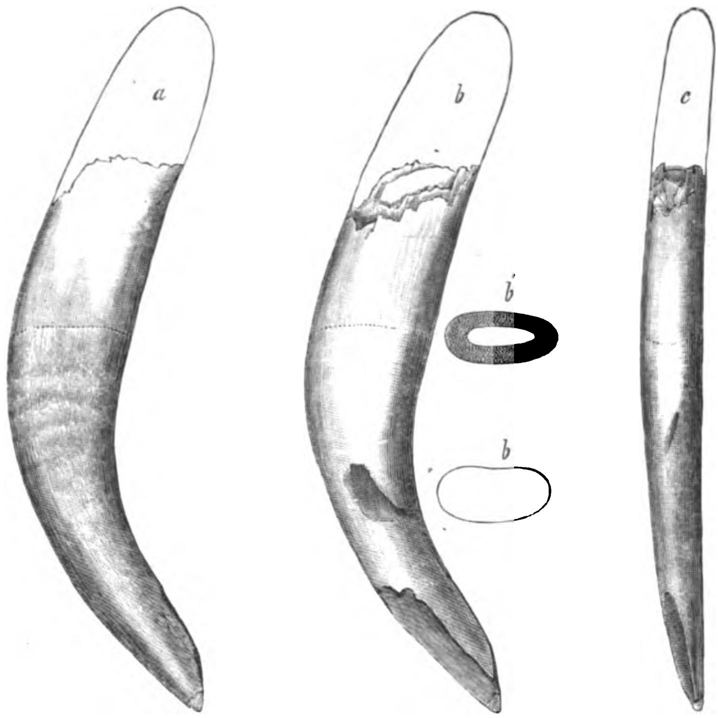


Fig. 86.—Upper canine of *Tinoceras grande*, Marsh; male.

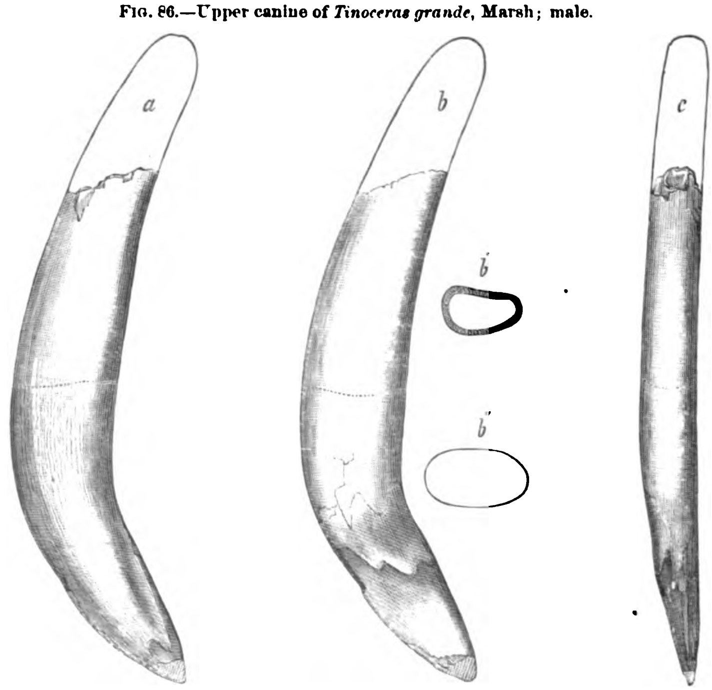


Fig. 87.—Upper canine of *Dinoceras laticeps*, Marsh; male. *a*, lateral view showing outer surface; *b*, inner surface; *b′ b″*, sections; *c*, front view.
All the figures are one-fourth natural size.

In *Dinoceras lucare* the upper canines are not constricted, but taper to the lower end, which also has a bayonet form.

In the female of *Dinoceras* the upper canines are small and slender, and protrude but little below the jaw.

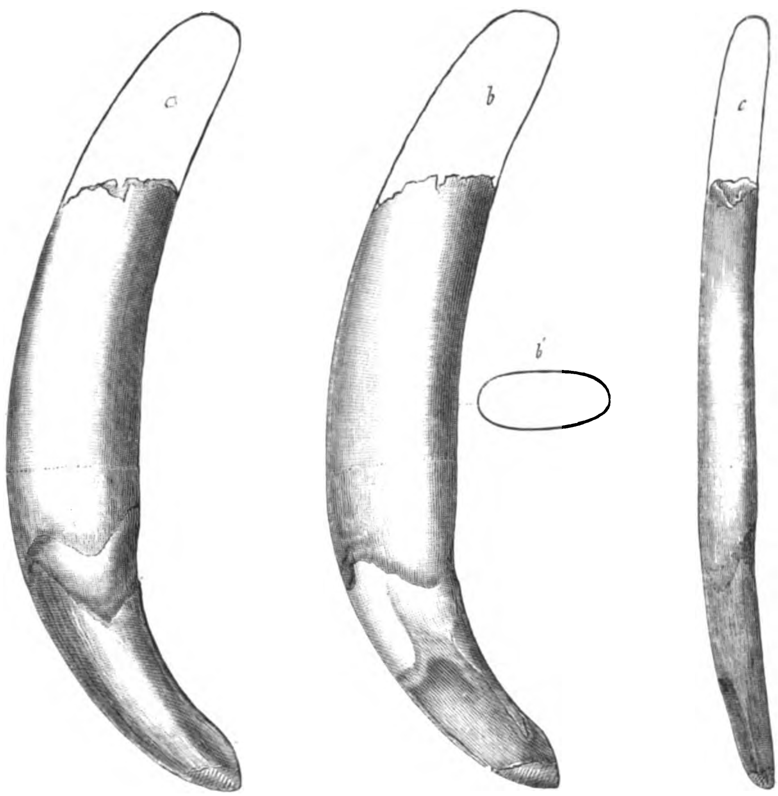


FIG. 88.—Upper canine of *Tinoceras ingens*, Marsh; male. *a*, lateral view showing outer surface; *b*, inner surface; *b' b''*, sections; *c*, front view.
All the figures are one-fourth natural size.

In *Tinoceras*, the upper canines are much more curved than in *Dinoceras*, and the end of the root, instead of being inserted in the base of the maxillary horn-core, starts well back of it, so that the general direction of this elevation is nearly at right angles to the tusk.

The general form of the upper canine tusks in the *Dinocerata* is shown in Figs. 83–89.

In the lower jaw of *Dinoceras*, the canine is very small, and very similar in form to the incisors, which it adjoins.

The same is true in the genus *Tinoceras*, where the lower canine, as well as the incisors, has a more erect position than in *Dinoceras*.

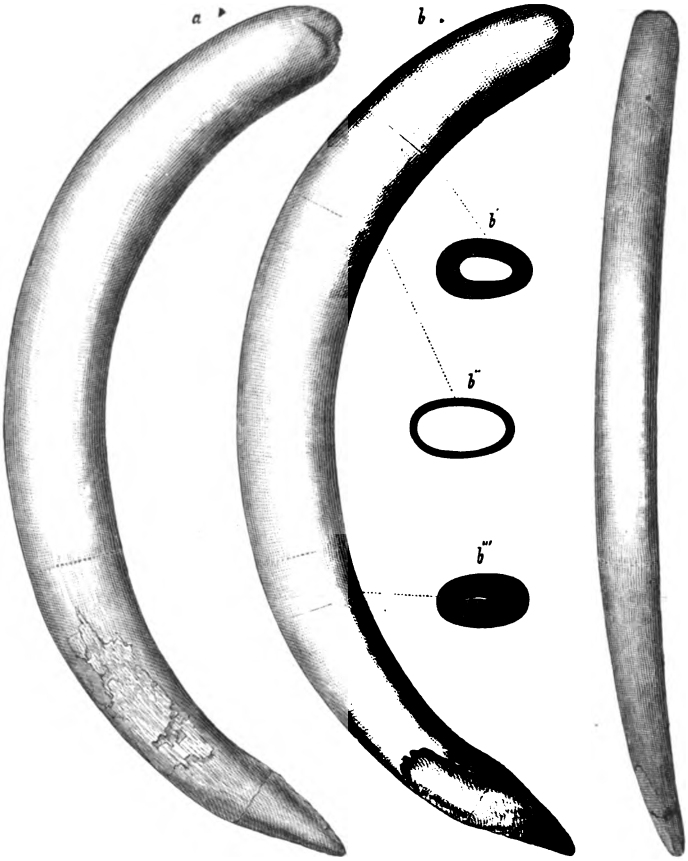


FIG. 89.—Upper canine of *Tinoceras pugnax*, Marsh; male. *a*, lateral view showing outer surface; *b*, inner surface; *b' b'' b,'''*, sections of tooth; *c*, front view.
All the figures are one-fourth natural size.

THE UPPER MOLARS.

The crowns of the premolar and molar teeth in *Dinoceras*, and, in fact, in all the known *Dinocerata*, are remarkably short, with the roots well developed, forming a true brachyodont dentition, as in all early Tertiary ungulates. These teeth are all inserted by three roots, two small ones on the outer side and a larger one on the inner side.

In the type of *Dinoceras mirabile*, the upper molar series is remarkably well preserved. The entire set of premolars and molars is in position, indicating that the animal was fully adult, and yet the amount of wear shown by these teeth is so slight as not to obscure in the least their essential characters.

There are three premolars and three true molars on each side, forming together a close series. There is in this skull no trace of what may be regarded as the first premolar. If present during the immature condition of the animal it has entirely disappeared. In one specimen of

this genus the alveole of this first upper premolar remains, but no other trace of the tooth has been seen.

In the genus *Tinoceras* the upper molar series is essentially the same in position and structure as in *Dinoceras*.

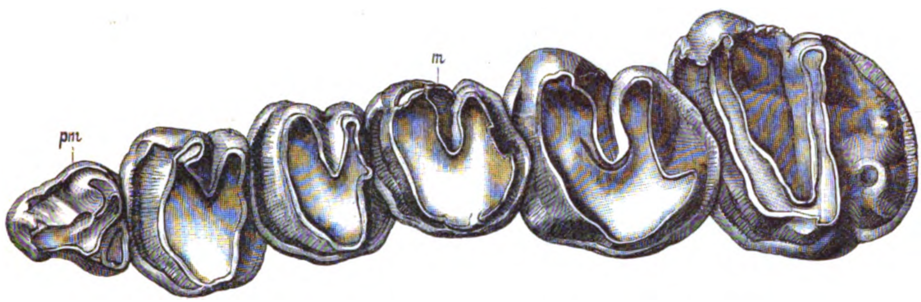


FIG. 90.—Upper molar series of *Tinoceras stenops*, Marsh; seen from below.

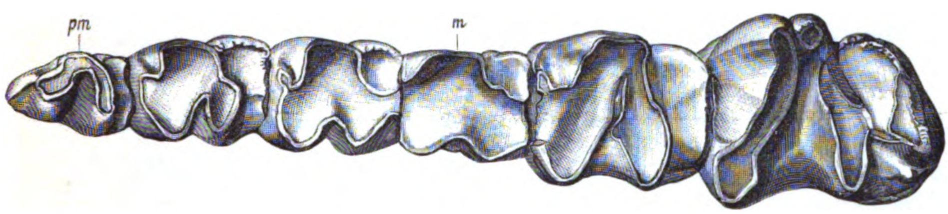


FIG. 91.—Lower molar series of same; seen from above. *m*, molar; *pm*, premolar. The figures are three-fourths natural size.

THE LOWER MOLARS.

In each ramus of the lower jaw of *Dinoceras* there is a close series of six teeth, three of which are premolars and three true molars. These are all inserted each by two roots. This is also true of the genus *Tinoceras*. In these two genera, so far as known, there is no indication of any premolar in front of this series.

All of the incisors, canines, and premolars in *Dinoceras* and *Tinoceras* appear to have been preceded by a series of temporary teeth. The incisors and lower canines sometimes made their appearance before their small predecessors had disappeared. In one specimen, represented in Figs. 76 and 77, page 275, these immature teeth are seen in place in small cavities in the sides of the alveolæ of the permanent dentition.

The lower incisors and their accompanying canines are usually more or less worn. This is due mainly to the food consumed, and in part to the attrition of the upper canines, and perhaps also to a heavy, coarse, upper lip. The premaxillaries, being edentulous, probably supported a pad, as in ruminants.

The upper canines show distinct traces of wear on their inner surface near the base, and also below, near the apex of the crown. This wear is probably due to the action of the agencies above described.

A more difficult problem is presented by the worn surface sometimes seen on the outer face of these tusks somewhat below the insertion in

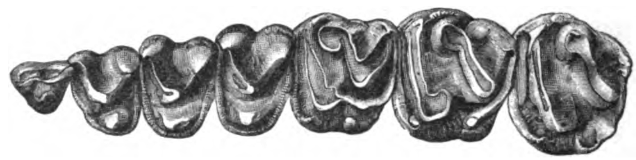


FIG. 92.—Upper molar series of *Coryphodon hamatus*, Marsh; seen from below.

FIG. 93.—Lower molar series of same specimen; seen from above.
Both figures are one-half natural size.

the jaw, as shown in Fig. 88, page 281. This is probably due to the wearing action of a heavy upper lip.

The molar teeth in *Dinocerata* appear to resemble more closely the corresponding teeth in the genus *Coryphodon* than those of any other animal. The general dentition, however, is quite distinct. *Coryphodon* has well-developed upper incisors and a medium-sized upper canine, thus differing widely in these features from the *Dinocerata*. The position and size of these teeth in *Coryphodon* are shown in Fig. 103, page 290. The upper and lower molar series are shown in Figs. 92 and 93.

THE BRAIN.

The brain of the *Dinocerata* is one of the most peculiar features of the group. It was especially remarkable for its diminutive size. It was proportionately smaller than in any other known mammal, recent or fossil, and even less than in some reptiles. It was, indeed, the most reptilian brain in any known mammal. In *Dinoceras mirabile* the entire brain was actually so diminutive that it could apparently have been drawn through the neural canal of all the pre-sacral vertebræ, certainly through that of the cervicals and the lumbars.

The size of the entire brain, as compared with that of the cranium, is shown in Figs. 44 and 45, page 260, and Figs. 94 and 95, page 285. The size of the brain cavity, and its position in the skull in the genus *Tinoceras*, also, is represented in Fig. 46, page 261.

The most striking feature in the brain cavity itself is the relatively small size of the cerebral fossa, this being but little larger than the cerebellar portion. This is well shown in Fig. 69, page 272.

The cerebral hemispheres did not extend at all over the cerebellum or the olfactory lobes. The latter were large, and continued well forward. The hemispheres were probably convoluted, and the sylvian fissure appears to be distinctly marked.

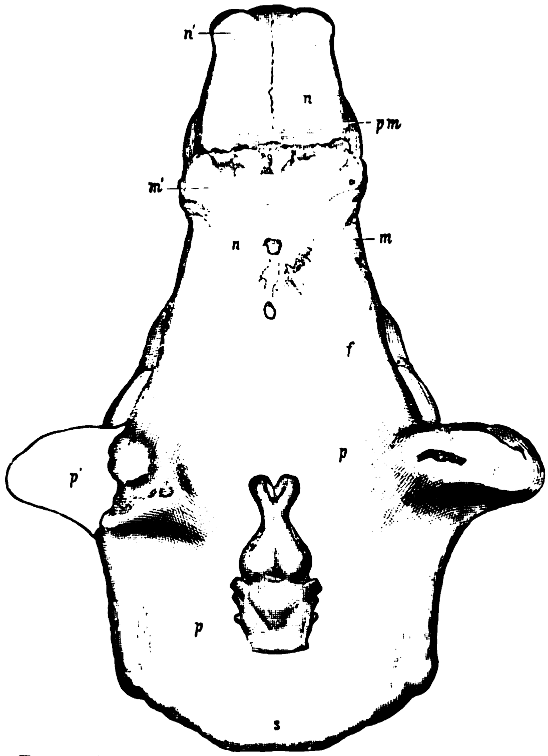


FIG. 94.—Skull of *Dinoceras laticeps*, Marsh; male; with brain-cast in position.

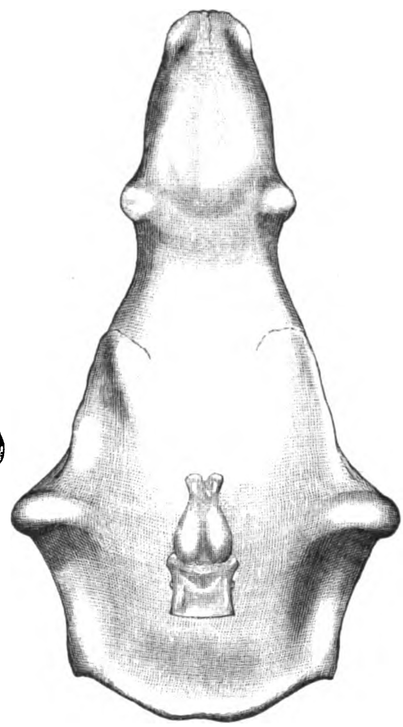


FIG. 95.—Skull of *Dinoceras laticeps*, female; with brain-cast in position.

Both figures are one-eighth natural size.

The cerebellar fossa is but little larger transversely than the medullar canal, and has lateral cavities, which were probably occupied by flocculi. There was a rudimentary tentorial ridge. The pituitary fossa is nearly round, and of moderate depth. There are no clinoid processes.

THE CRANIAL NERVES.

The nerves passing off from the brain were large, and can be made out with reasonable certainty. The olfactory lobes were separated in front by an osseous septum, the position of which is shown distinctly in Figs. 94 and 95.

The cribriform plate, bounding these lobes in front, is thin and easily displaced, but its position in the specimens is shown approximately by the extremity of the olfactory lobes represented in the same figures. In front of this plate, the olfactory nerves were spread out in a large cavity, which is represented in Figs. 65–68, pages 270–271. The nasal canals extend forward from this cavity to the external nares, as indicated in

the same figures. In these canals there were thin, well-developed, ethmo-turbinal bones, which were easily displaced and broken up. The presence of these bones is strong evidence that there was no proboscis.

The optic nerves, or second pair, were well developed. Their position, size, and place of exit are shown in Figs. 96 and 98.

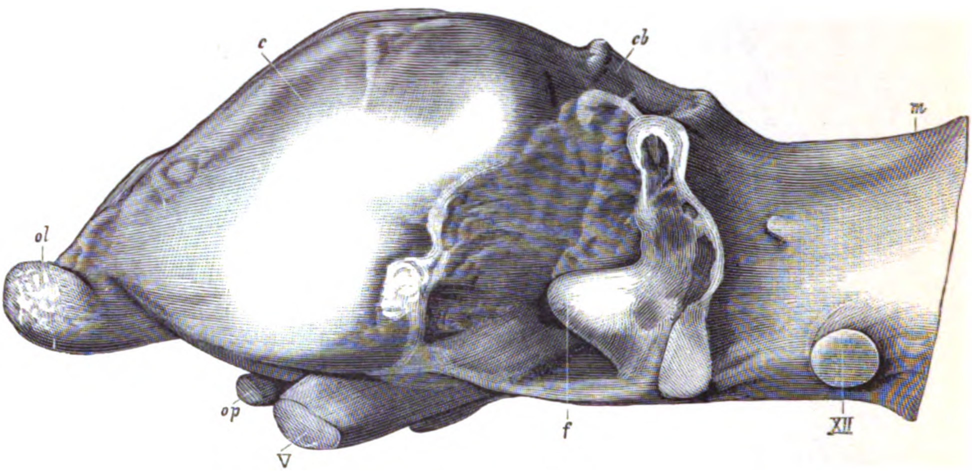


FIG. 96.—Cast of brain-cavity of *Tinoceras ingens*, Marsh; side view.

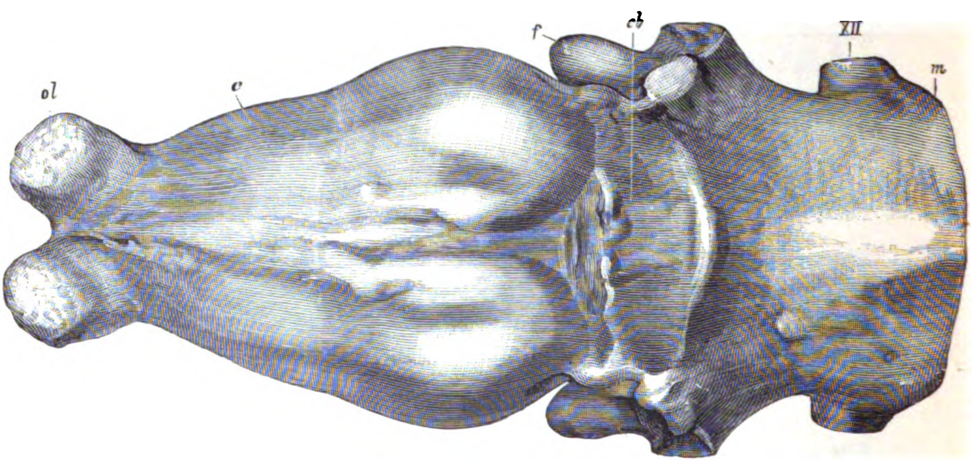


FIG. 97.—The same; superior view: *c*, cerebral hemispheres; *cb*, cerebellum; *f*, flocculus; *m*, medulla; *ol*, olfactory lobes; *op*, optic nerves; V, fifth nerve; XII, twelfth nerve.
Both figures three-fourths natural size.

The fifth pair of nerves, or tri-geminals, was very large, and are given off on either side, behind the optics, and opposite the depression for the pituitary body.

The sixth pair of nerves passed off immediately behind and below the fifth pair. The twelfth pair, or hypoglossal nerves, passing off through the condylar foramina, were large, and their position is given in the same

figures. The position and exit of the other nerves given off from the brain cannot be determined with certainty.

In the genus *Tinoceras* the brain was similar in its general characters to that of *Dinoceras*, but appears to have been somewhat more highly

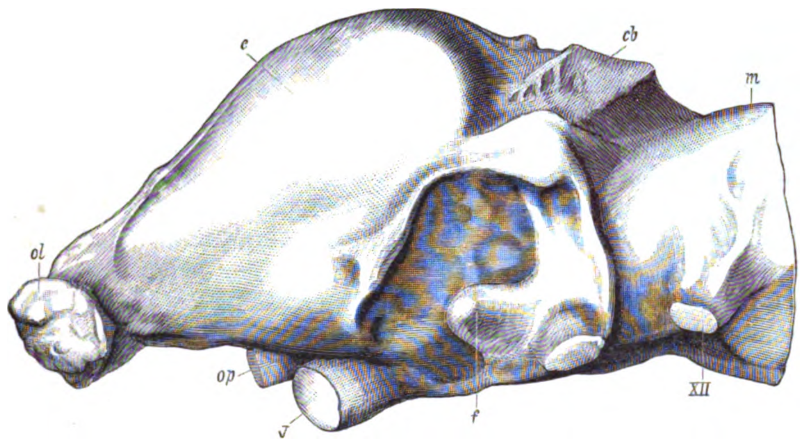


FIG. 98.—Cast of brain cavity of *Uintatherium robustum*, Leidy; type specimen, lateral view,

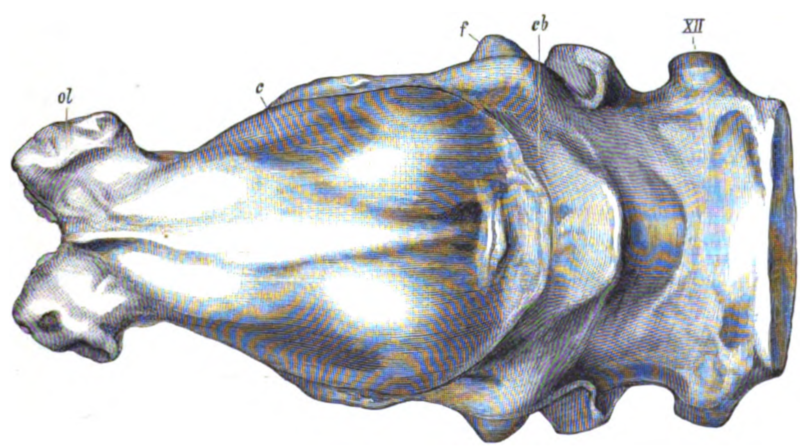


FIG. 99.—The same, superior view. *c*, cerebral hemispheres; *cb*, cerebellum; *f*, flocculus; *m*, medulla; *ol*, olfactory lobes; *op*, optic nerves; V, fifth nerve; XII, twelfth nerve.
Both figures three-fourths natural size.

developed, as shown in Figs. 96 and 97, page 286. The hemispheres were more elongate, and the olfactory lobes relatively smaller. The cavities for the flocculi were quite large, and directed well forward. The twelfth pair of nerves was largely developed.

In *Uintatherium*, the brain of the type specimen was nearly, or quite, as small as in *Dinoceras*. The hemispheres were short, and moderately

expanded transversely. The olfactory lobes were separated by a wide septum, and were more divergent than in *Dinoceras* or *Tinoceras*. These characters are shown in Figs. 98 and 99, page 287.

BRAIN GROWTH.

The *Dinocerata* are, by far, the largest of all known Eocene animals, and that they have, also, a very diminutive brain is a noteworthy fact, which attracted the writer's attention soon after their discovery.

The comparison of the brain in this group with that of other mammals from the same formation soon showed that the *Dinocerata*, although most remarkable in this respect, were not alone in diminutive capacity of brain power. A more extended comparison soon led to the fact that all of the early Tertiary mammals had very small brains, and in many of them the brain was of a low, almost reptilian type. As the comparison was extended to include the mammals from the higher divisions of the Eocene, and also from the Miocene, the same fact became more apparent; but, in extending the investigation to the animals of more recent geological age, a gradual increase in size and quality of the brain soon became evident. In bringing into the investigation the mammals from the Pliocene and Quaternary, the improvement in brain power became still more apparent, and the outline of a general law of brain growth was soon determined.

In tracing thus the different groups of mammals, each from the early Tertiary to the present time, it was found that in every series where the material was sufficient to make a fair comparison the brain growth had been constant, and followed the same general law.

The results of this investigation were embodied by the writer in a general law of brain growth in the extinct mammals throughout Tertiary time. This law, briefly stated, is as follows:

1. All Tertiary mammals had small brains.
2. There was a gradual increase in the size of the brain during this period.
3. This increase was confined mainly to the cerebral hemispheres, or higher portion of the brain.
4. In some groups the convolutions of the brain have gradually become more complex.
5. In some, the cerebellum and the olfactory lobes have even diminished in size.
6. There is evidence that the same general law of brain growth holds good for Birds and Reptiles from the Cretaceous to the present time.[4]

The writer has since continued this line of investigation, and has ascertained that the same general law of brain growth is true for birds and reptiles, from the Jurassic to the present time.

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[4] *American Journal of Science and Arts*, Vol. VIII, p. 66, July, 1874, and Vol. XII, p. 61, July, 1876; also Odontornithes, p. 10, 1880.

To this general law of brain growth, two additions may now be made, which, briefly stated, are as follows:

(1) The brain of a mammal belonging to a vigorous race, fitted for a

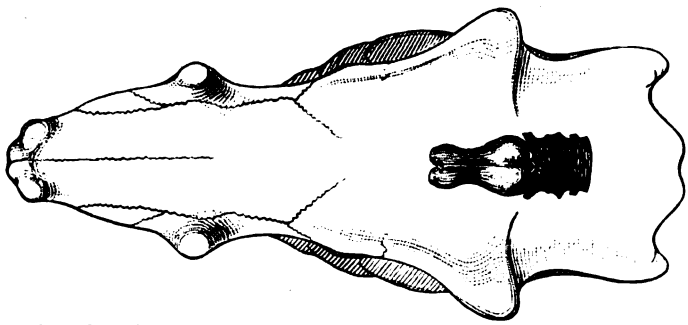


FIG. 100.—Outline of skull of *Dinoceras mirabile*, Marsh, with cast of brain cavity in position; one-eighth natural size. Eocene.

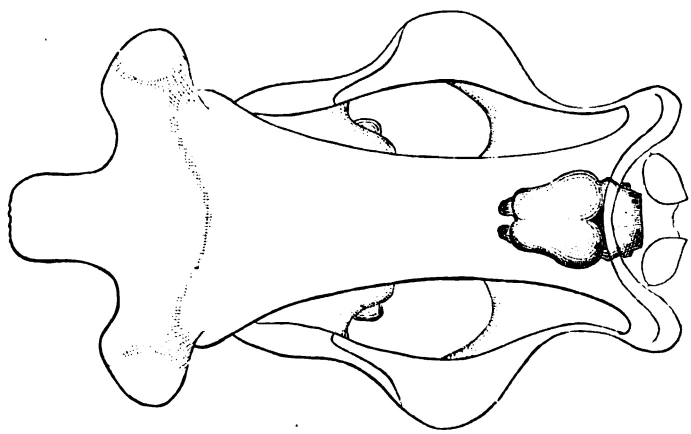


FIG. 101.—Outline of skull of *Brontotherium ingens*, Marsh, with cast of brain cavity in position; one-tenth natural size. Miocene.

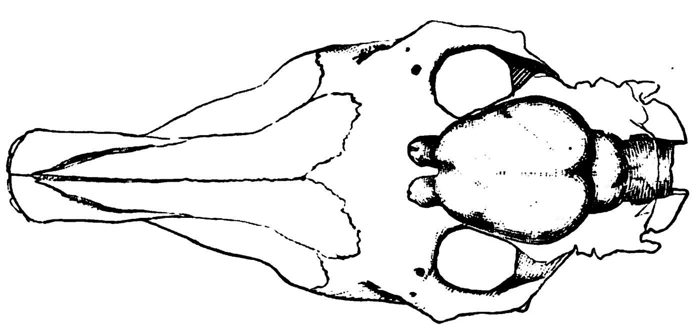


FIG. 102.—Outline of skull of horse, *Equus caballus*, Linn, with cast of brain cavity in position; about one-sixth natural size. Recent.

long survival, is larger than the average brain of that period in the same group.

(2) The brain of a mammal of a declining race is smaller than the average of its cotemporaries of the same group.

These results of the study of the whole subject of brain growth the writer intends to bring together in a separate memoir. Some of the facts, however, may be appropriately presented in the present article in connection with the brain characters of the *Dinocerata*, which naturally form the beginning of one series in the investigation.

In any comparison of the size of the brain in different animals, whether in the same group or in others widely different, it is important to bear in mind that:

1. The brain of small animals is proportionally larger in bulk than that of large animals.

2. The brain of young animals is proportionally larger than in those fully adult.

In a general comparison of brain growth of mammals, the first of these facts can only have a limited effect, which would not change essentially the general results. The effects of the second fact may be readily eliminated by confining the comparison to adult animals.

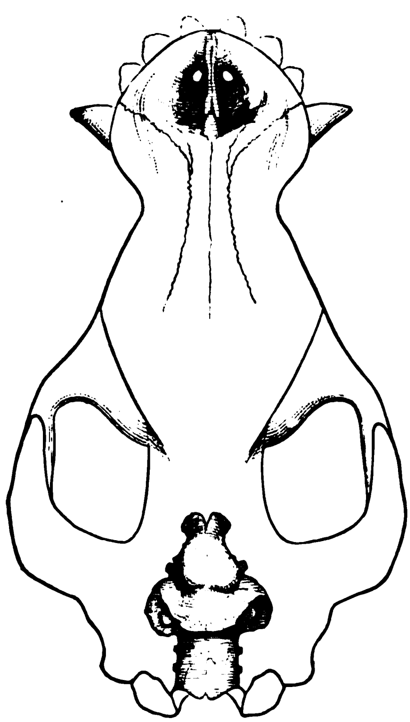


FIG. 103.—Skull of *Coryphodon hamatus*, Marsh. Lower Eocene.

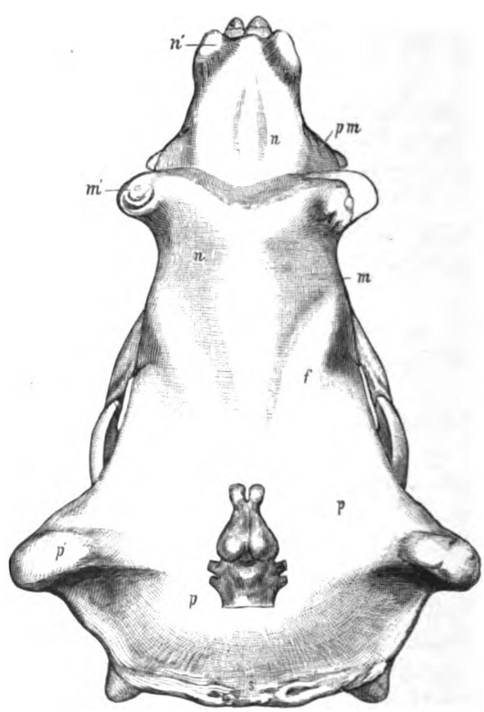


FIG. 104.—Skull of *Tinoceras pugnax*, Marsh. Middle Eocene.

In this comparison, moreover, of the extinct forms with those of more modern time, including recent mammals, it may be taken for granted

that the brain cavity of the extinct forms, as well as of those now living, was entirely filled by the brain; since, with possibly a single exception, no mammal is known in which this is not the case.

In comparing the size of the brain in mammals with that of reptiles and fishes an important point to be borne in mind would be the fact

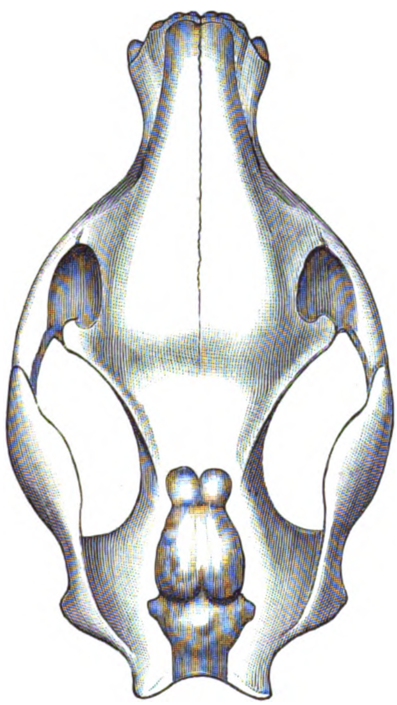


FIG. 105.—Skull of *Limnohyus robustus*, Marsh. Middle Eocene.

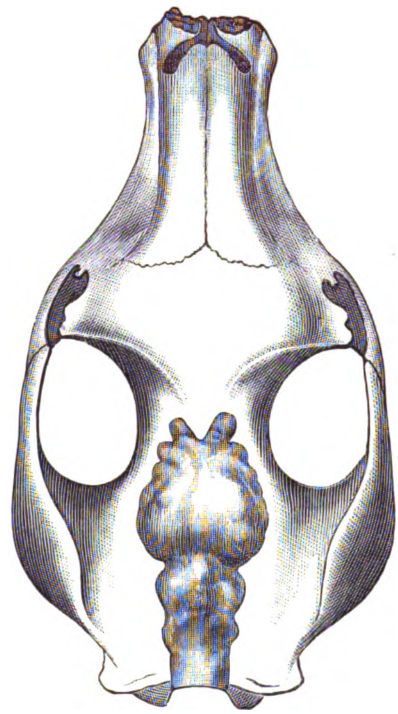


FIG. 106.—Skull of *Amynodon advenus*, Marsh. Upper Eocene.

that in the two latter classes the brain cavity is not always entirely filled by the brain. The present comparison deals with mammals alone, and this restriction is here of no importance.

The fact that among existing mammals there are some anomalous features in the size of the brain in allied groups, has not been forgotten, but such instances, even if they occurred among extinct mammals, would not materially affect the comparison here proposed.

In the following pages a series of figures is given, showing the comparative size of the brain, and its position in the skull in a number of ungulate mammals, recent and extinct. To make the comparison a fair one, the skulls are all drawn of the same absolute size, thus showing at once the relative proportion of the brain in each. The skulls are placed horizontally, the plane of the molar teeth being as a rule taken as a base. In the case of artiodactyls, this position has been somewhat changed, as in this group of ungulates the brain is more or less

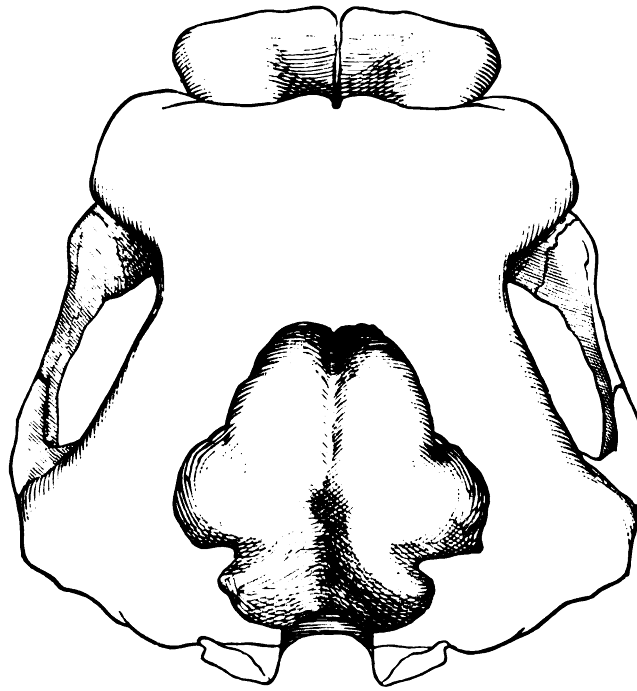


FIG 107.—Skull of *Mastodon Americanus*, Cuvier. Pliocene.

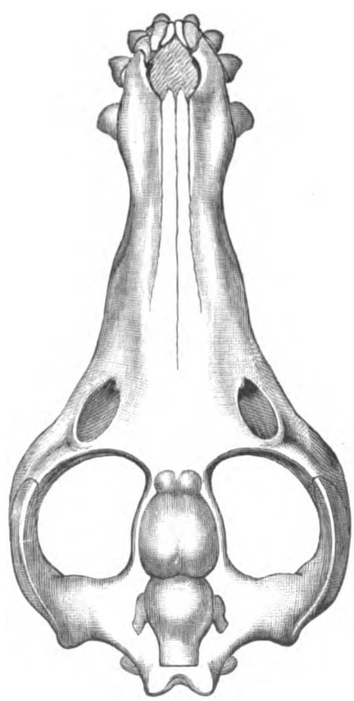


FIG. 108.—Skull of *Elotherium crassum*, Marsh. Miocene.

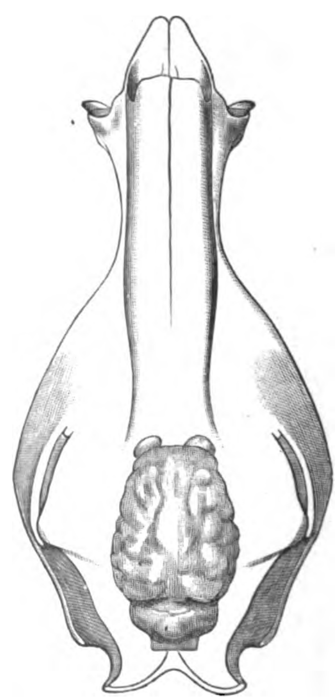


FIG. 109.—Skull of *Platygonus compressus*, LeConte. Pliocene.

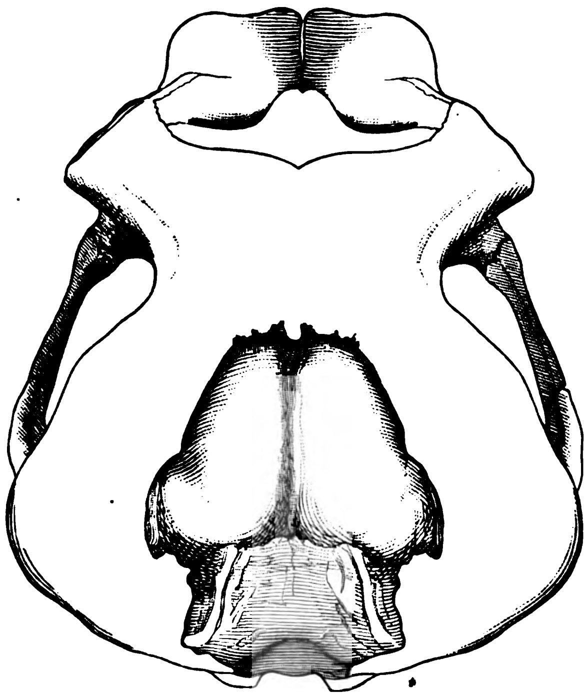


FIG. 110.—*Elephas Indicus*, Linnæus. Recent.

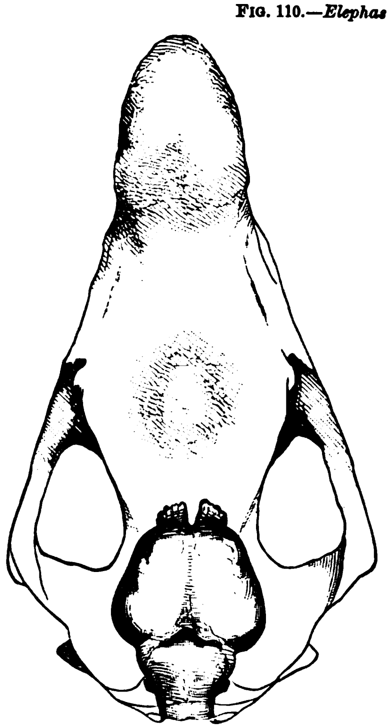


FIG. 111.—*Rhinoceros Sumatrensis*, Cuvier. Recent.

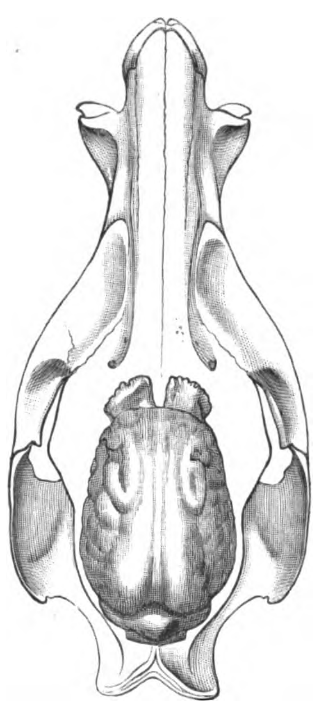


FIG. 112.—*Dicotyles torquatus*, Cuvier. Recent.

inclined backward in the skull. In these cases the angle of inclination of the face and of the brain is made equal, thus giving to both the best position for comparison.

A striking illustration of the development of the brain from the early Tertiary to the present time may be seen in Figs. 100–102, page 289, where is shown, first, the skull of *Dinoceras*, the largest mammal of the Eocene, with the brain in position; second, the skull of the gigantic Miocene *Brontotherium*, with the brain also in position; and third, the skull of the recent horse. Other comparisons, equally striking, can readily be made.

The small size of the brain in early Tertiary mammals will be indicated by an examination of the *Dinocerata* skulls, with the brain in position, shown in Figs. 44–46, pages 260, 261. This is further shown by Fig. 103, page 290, which represents the skull and brain of *Coryphodon*, the largest mammal in the lower Eocene, from beds of earlier age than those containing the *Dinocerata*, as shown in the section, Fig. 37, page 253.

The size of the brain in the middle Eocene *Limnohyus* is shown in Fig. 105, page 291. *Amynodon* from the upper Eocene is represented in Fig 106, on the same page.

The larger brain of the Miocene mammals is indicated by the Fig. 101, page 289, showing the skull of *Brontotherium*, which is found at the base of the Miocene, as shown in Fig. 37, page 253. *Elotherium* from the same horizon is represented in Fig. 108.

The still more developed brain of the Pliocene mammals is seen in Fig. 107, page 292, which gives a view of the skull of the Mastodon, with the brain in position. In Fig. 109, the skull and brain of an extinct Pliocene peccary further illustrates the same law of brain growth.

On comparing these various figures with those representing the brains and skulls of the existing Ungulates, as shown by the succession in Figs. 110–112, on page 293, the reader will have before him a series of facts which illustrate the laws of brain growth given on page 288. The comparison, here confined to the representative ungulate mammals, might easily be extended much farther, but would not come within the scope of the present article.

The writer has made similar comparisons in other groups of mammals, including those from the early Tertiary to the present time, and the results are almost uniformly the same.

THE VERTEBRÆ.

The vertebræ of the *Dinocerata*, in their main characters, resemble those of Proboscidians. The atlas and axis are somewhat similar to those of the elephant, but the rest of the cervicals are proportionally longer. The atlas is a massive bone, presenting the ordinary articular

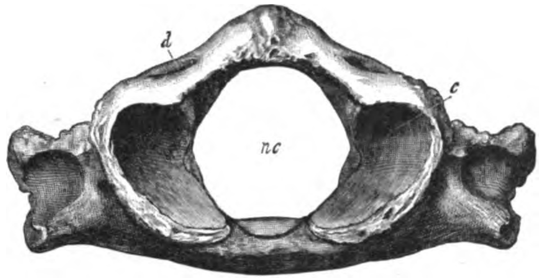


FIG. 113.—Atlas of *Tinoceras grande*, Marsh, front view.

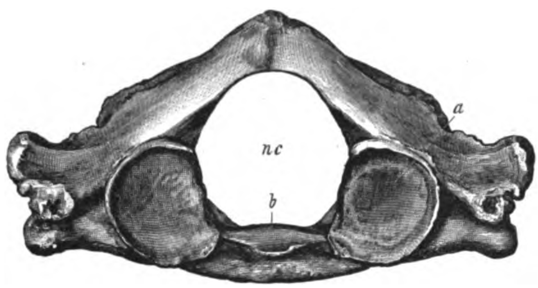


FIG. 114.—The same vertebra, back view.

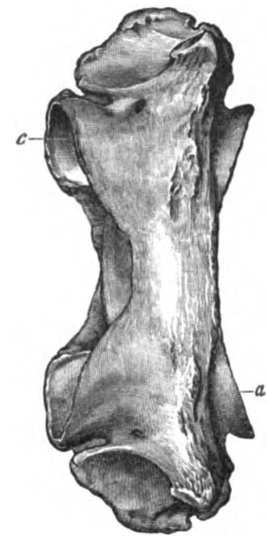


FIG. 115.—The same bottom view.

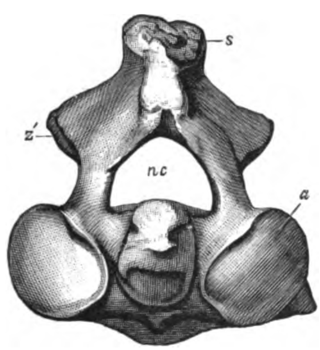


FIG. 116.—Axis of *Dinoceras mirabile*, Marsh, front view.

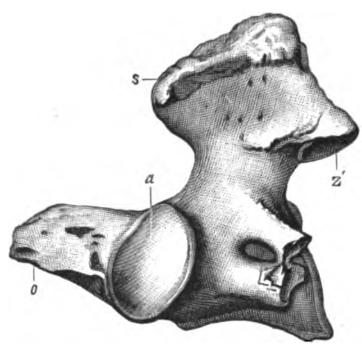


FIG. 117.—The same vertebra, side view.

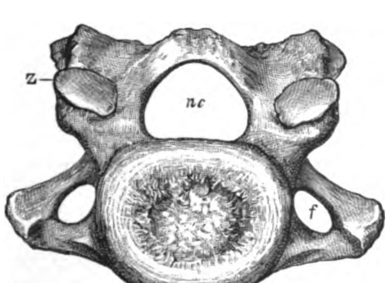


FIG. 118.—Cervical vertebra of *Dinoceras cuneum*, Marsh, front view.

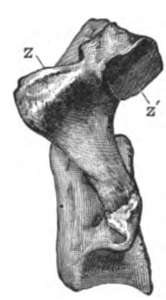


FIG. 119.—The same, side view.

a, face for axis; *a'*, face for atlas; *b*, face for odontoid process; *c*, face for occipital condyles; *f*, lateral foramen; *n c*, neural canal; *o*, odontoid process; *s*, neural spine; *z*, anterior zygapophysis; *z'*, posterior zygapophysis.

All the figures are one-fourth natural size.

faces of this vertebra. The anterior pair of these for the reception of the occipital condyles are well separated above and below. The poste-

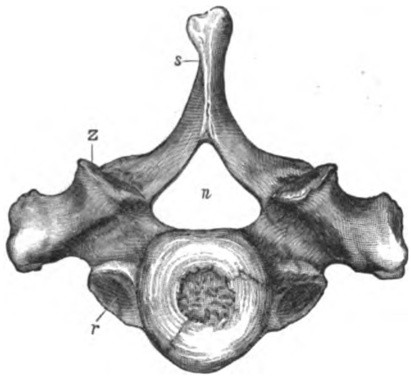


FIG. 120.—First dorsal vertebra of *Dinoceras mirabile*, Marsh, front view.

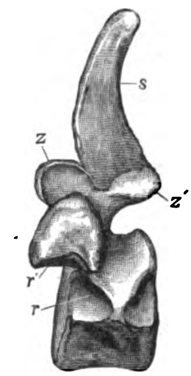


FIG. 121.—The same vertebra, side view.

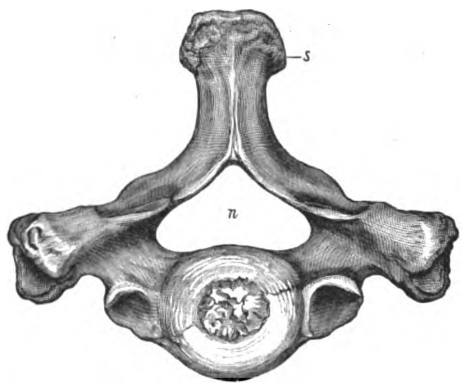


FIG. 122.—Second dorsal vertebra of the same species, front view.

FIG. 123.—The same vertebra, side view.

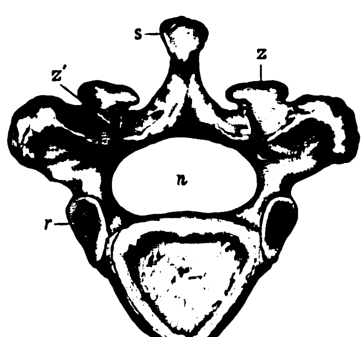


FIG. 124.—Posterior dorsal of *Dinoceras lucare*, Marsh.

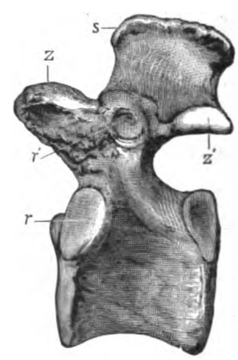


FIG. 125.—The same vertebra, side view.

n, neural canal; *r*, face for head of rib; *r'*, face for rib tubercle; *s*, neural spine; *z*, anterior zygapophysis; *z'*, posterior zygapophysis.

All the figures are one-fourth natural size.

rior faces for the articulation of the second vertebra, or axis, are also widely separated from each other. All three are subcircular in form,

the lateral ones somewhat excavated. The articulation between the atlas and axis can have admitted but little rotary motion to the head. The spine of the atlas is not well marked. The principal characters of this vertebra are shown in Figs. 113–115, page 295.

The axis, or second vertebra, is short and robust. The odontoid

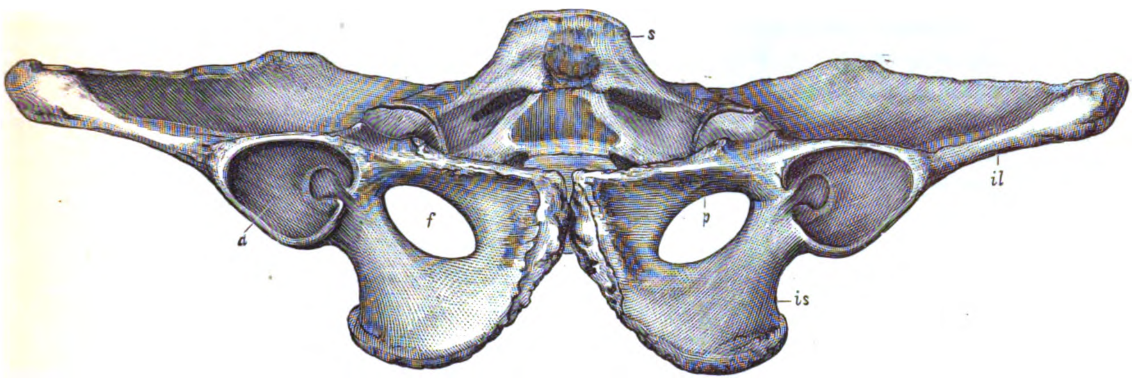


FIG. 126.—Pelvis of *Tinoceras ingens*, Marsh, bottom view.

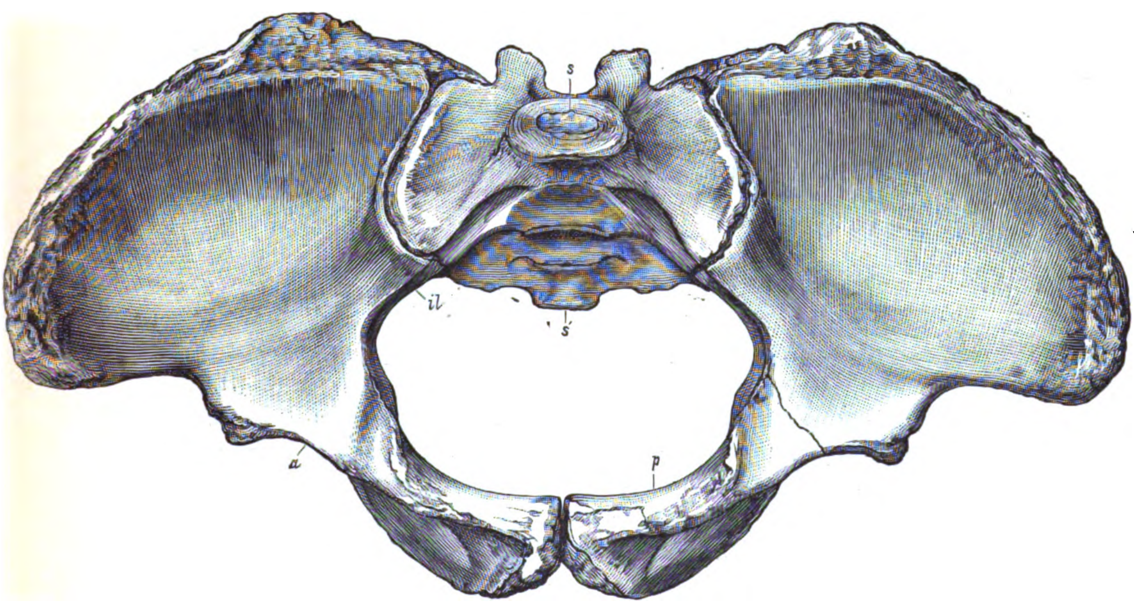


FIG. 127.—The same, front view. *a*, acetabulum; *f*, obturator foramen; *il*, ilium; *is*, ischium; *p*, pubis; *s*, anterior end of sacrum; *s'*, posterior end of sacrum. Both figures are one-eighth natural size.

process is distinctly peg-shaped, and not at all excavated above. The neural arch is massive. The transverse processes are short and strong, and were pierced by a foramen for the passage of the vertebral artery. This vertebra is represented in Figs. 116 and 117, page 295.

The cervical vertebræ behind the axis are short, and concave on both

ends, the posterior faces being slightly more excavated than the anterior. The length of each centrum is less than its vertical diameter, and the transverse diameter is greater than the vertical.

The pedicils of all the cervical vertebræ are short and robust. The vertebrarterial foramina are oval, with the long diameter oblique. The fourth cervical vertebra is represented in Figs. 118 and 119, page 295.

The first dorsal vertebra has the articular faces nearly flat. The neural spine is weak. The transverse processes are short and strongly tuberculated at the end. The articular faces for the heads of the first and second ribs are of equal size, and suboval in outline. This vertebra is shown in Figs. 120 and 121, page 296. The dorsal vertebræ further back have more massive and more elevated neural spines. The transverse processes are short and robust. The neural canal is large. An anterior dorsal vertebra is shown in Figs. 122 and 123, page 296. The posterior dorsal vertebræ have short neural spines, and the centrum is wedge-shaped below, or sub-triangular in outline, when seen from the ends. One of these vertebræ is shown in Figs. 124 and 125.

The lumbar vertebræ have the centra distinctly wedge-shaped below. The neural spine is short and weak, and compressed laterally. The transverse processes are elongate, thin, and horizontal.

There are four sacral vertebræ, the last being quite small. These are shown in Figs. 126 and 127, page 297.

The anterior caudal vertebræ have long and depressed transverse processes.

The distal caudals were cylindrical, and of moderate length.

RIBS AND STERNUM.

The ribs of the *Dinocerata* present no special characters of importance, but resemble in general those of the mastodon. Their number and general form are shown sufficiently well in the restorations of *Dinoceras* and *Tinoceras*, Figs. 136 and 137. The sternum is of more interest and is peculiar in having its different elements horizontal, thus resembling the sternal bones in the Artiodactyls. The ribs were connected with the sternum by cartilaginous segments which are not preserved.

THE FORE LIMBS.

The limb bones in the *Dinocerata* are solid, and this is true of all the skeleton, a portion of the skull alone excepted. The scapula, in its general form, is similar to that of the elephant, but there is much less constriction above the glenoid fossa. The latter is elongate, deeply

concave longitudinally, and nearly flat transversely. The spine extends downward nearly to the glenoid border. The coracoid portion is a

FIG. 128.—Left fore foot of *Eporeodon socialis*, Marsh.

FIG. 129.—Left hind foot of same.

Both figures are one-third natural size.

rugose protuberance, separate from the margin of the articular fossa. The scapula is shown in Fig. 137.

The humerus is short and massive, and in its main features resem-

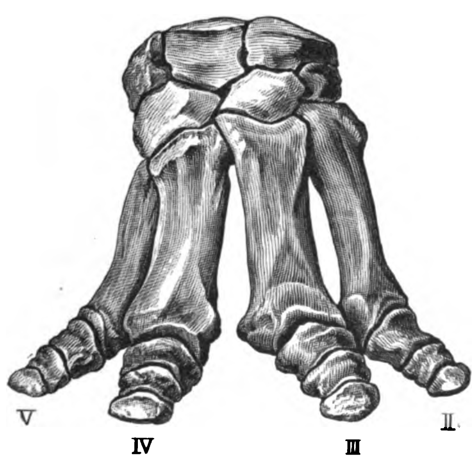


FIG. 130.—Right fore foot of *Brontotherium ingens*, Marsh.

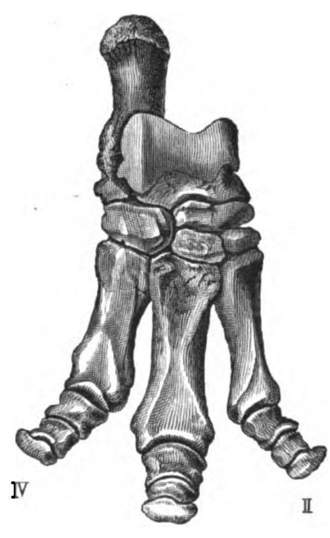


FIG. 131.—Right hind foot of same.

Both figures are one-sixth natural size.

bles that of the elephant. One of the most marked differences is seen in the great tuberosity, which does not rise above the head and is

but little compressed. The condylar ridge, moreover, of the distal end is tubercular, and not continued upward on the shaft. The lower extremity of the humerus is much like that of the rhinoceros, and the proportions of the two bones are essentially the same. The radius and ulna are nearly of the same size. The head of the radius rests on the middle of the ulnar articulation, and hence the shaft of this bone does not cross that of the ulna so obliquely as in the elephant. The ulna has a small face for articulation with the lunar, as in the elephant. These bones are shown in the restorations, Figs. 136 and 137.

There are five well-developed toes in the fore foot of *Dinoceras*, which is well shown in Fig. 134. The carpal bones are eight in number and form interlocking series, as in Perissodactyls. The scaphoid resembles that bone in the elephant, but is shorter and stouter. Its proximal end is rounded, forming about one-fourth of a sphere. On its distal end the articular faces are confluent. It supports the trapezium and trapezoid. The pyramidal sends down an outer angle to articulate with the metacarpal, as in *Elephas*. The trapezoid is the smallest bone in the carpus. The magnum is supported by the lunar, and not at all by the scaphoid. The unciform is the largest carpal bone. It has the usual metacarpal faces, well marked and separated by ridges. The metacarpals are of moderate length, and the third is about equally supported by the magnum and unciform. The articulations for the phalanges are nearly flat, indicating but little motion. The phalanges are very short, and the distal ones rugose. The entire fore foot is shown in Fig. 134. The resemblance to the fore foot in *Coryphodon*, Fig. 132, is marked, and in a less degree to that of *Brontotherium* (Fig. 130). The latter is an example of a Perissodactyl foot. Fig. 128 shows a fore foot of the Artiodactyl type.

THE PELVIS.

The pelvis is much expanded, as in Proboscidians. The ilium is suboval in outline. The pubis is slender and short, and the ischium has less posterior extension than in the elephant. The thyroid foramen is an elongate oval. Two views of the pelvis are represented in Figs. 126 and 127, page 297.

THE HIND LIMBS.

The femur is proportionally about one-third shorter than that of the elephant. The head of this bone has no pit for the round ligament, and the great trochanter is flattened and recurved. There is no indication

of a third trochanter. The distal end of the femur is more flattened transversely than in the elephant, and the condyles are more nearly of the same size. The corresponding articular faces of the tibia are consequently about equal, and also contiguous, with no prominent elevation between them. When the limb was at rest the femur and tibia were nearly in the same line, as in the elephant and in man. The patella is elongate, and oval in outline. The fibula is slender and entire, with articular faces well marked at each extremity. The bones of the hind limbs are shown in position in the restorations, Figs. 136 and 137.

FIG. 132.—Left fore foot of *Coryphodon hamatus*, Marsh.

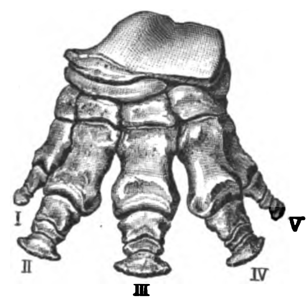


FIG. 133.—Left hind foot of the same.

Both figures are one-third natural size.

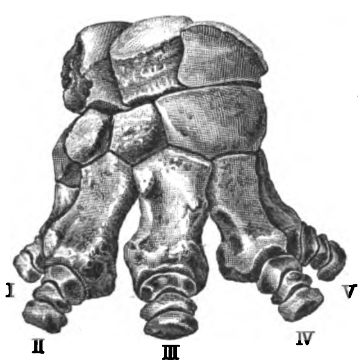


FIG. 134.—Left fore foot of *Dinoceras mirabile*, Marsh.

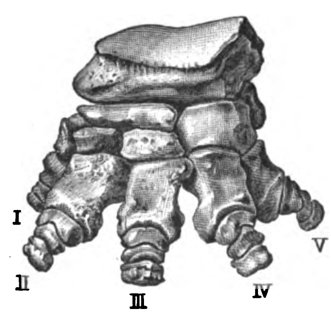


FIG. 135.—Left hind foot of the same.

Both figures are one-fifth natural size.

The astragalus has no distinct superior groove. Its anterior portion has articular faces for both the navicular and cuboid, thus differing from Proboscidians, and agreeing with Perissodactyls. The calcaneum is very short, its longitudinal and transverse diameters being about equal. It does not articulate with the navicular, as in the elephant, and has only a small face for the cuboid. There are four well-developed digits in the pes, and a rudimentary or small hallux. The metatarsals are much shorter than the metacarpals. The phalanges and sesamoid bones are smaller, but otherwise similar to those of the manus. The hind foot of *Dinoceras* is shown in Fig. 135.

RESTORATION.

In Fig. 136 below, a restoration is given of the skeleton of *Dinoceras mirabile*, the type of the genus *Dinoceras*, and of the order *Dinocerata*. The animal is represented as walking, and the reduced figure is one-thirtieth of natural size.

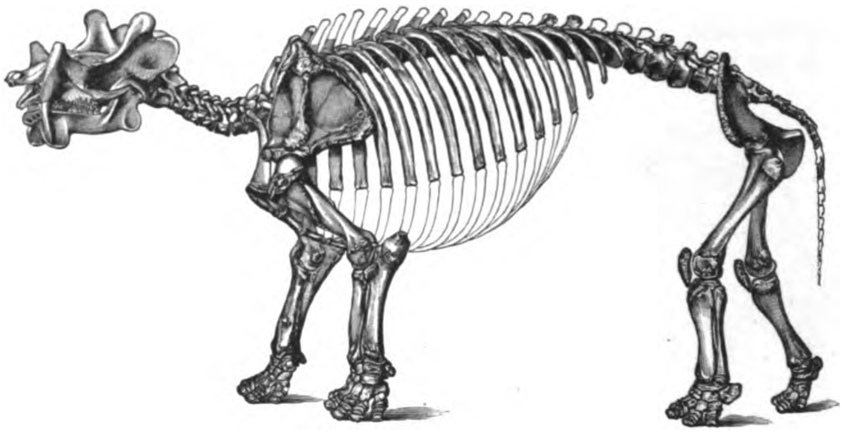


FIG. 136.—Restoration of *Dinoceras mirabile*, Marsh.

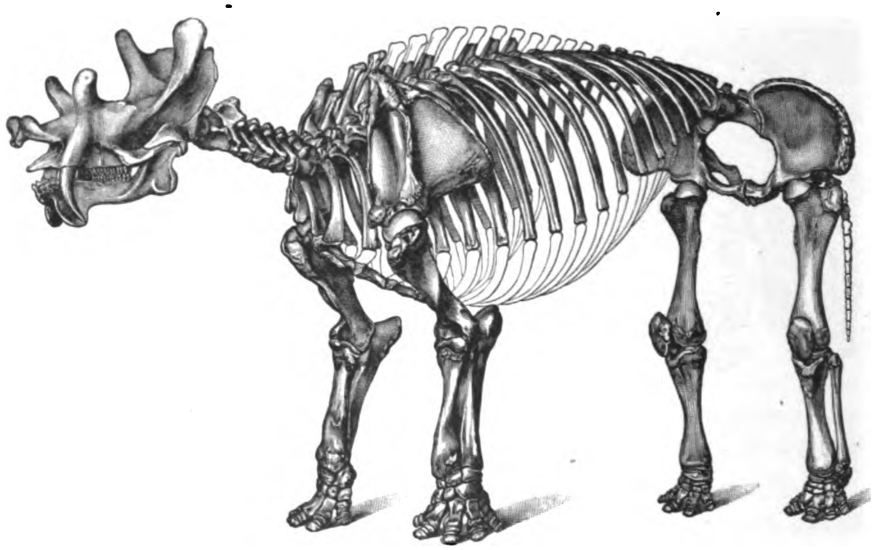


FIG. 137.—Restoration of *Tinoceras ingens*, Marsh.
Both figures are one-thirtieth natural size.

In Fig. 137, on the same page, is a restoration of *Tinoceras ingens*, a characteristic species of the genus *Tinoceras*. This figure is also one-thirtieth of natural size, and the animal is represented standing at rest.

These two figures are taken from the large lithographic plates of a monograph by the writer on the *Dinocerata* which is now in press. In this memoir the reader will find full descriptions and illustrations of the animals belonging to this order of extinct gigantic mammals.

EXISTING GLACIERS

OF THE

UNITED STATES.

BY

ISRAEL C. RUSSELL.

CONTENTS.

ILLUSTRATIONS.

EXISTING GLACIERS OF THE UNITED STATES.

By Israel C. Russell.

WHAT IS A GLACIER?

Glaciers have become as well known from the graphic descriptions of Carpenter, Forbes, Agassiz, Tyndall, and other explorers, that it seems unnecessary at this time to do more than call attention to a few of their more characteristic features by way of an introduction to what I have written concerning those now existing in the United States.

The formation of glaciers in any region depends primarily on the fact that the amount of snow precipitated during a term of years exceeds the amount dissipated by melting and evaporation. In this manner snow banks of broad extent are formed, the lower portions of which become compacted into ice. The change from snow to ice is known to result from pressure, and as ice is mobile under pressure, either by reason of its inherent plasticity or as a result of regelation, the weight of this mass tends to change its form, and it thus acquires motion, which takes the direction of least resistance.

The essential characteristic of glaciers seems to be that they result from the consolidation of snow in regions of secular accumulation, *i. e.*, above the snow-line, and flow to regions of dissipation, *i. e.*, below the snow-line. From these primary conditions result a multitude of secondary phenomena.

For convenience of reference we will divide glaciers into *alpine* and *continental;* not that the two classes are always distinct and separable, but for the reason that typical examples of each are well characterized and capable of specific description. Variations occur in each class which may suggest minor subdivisions.

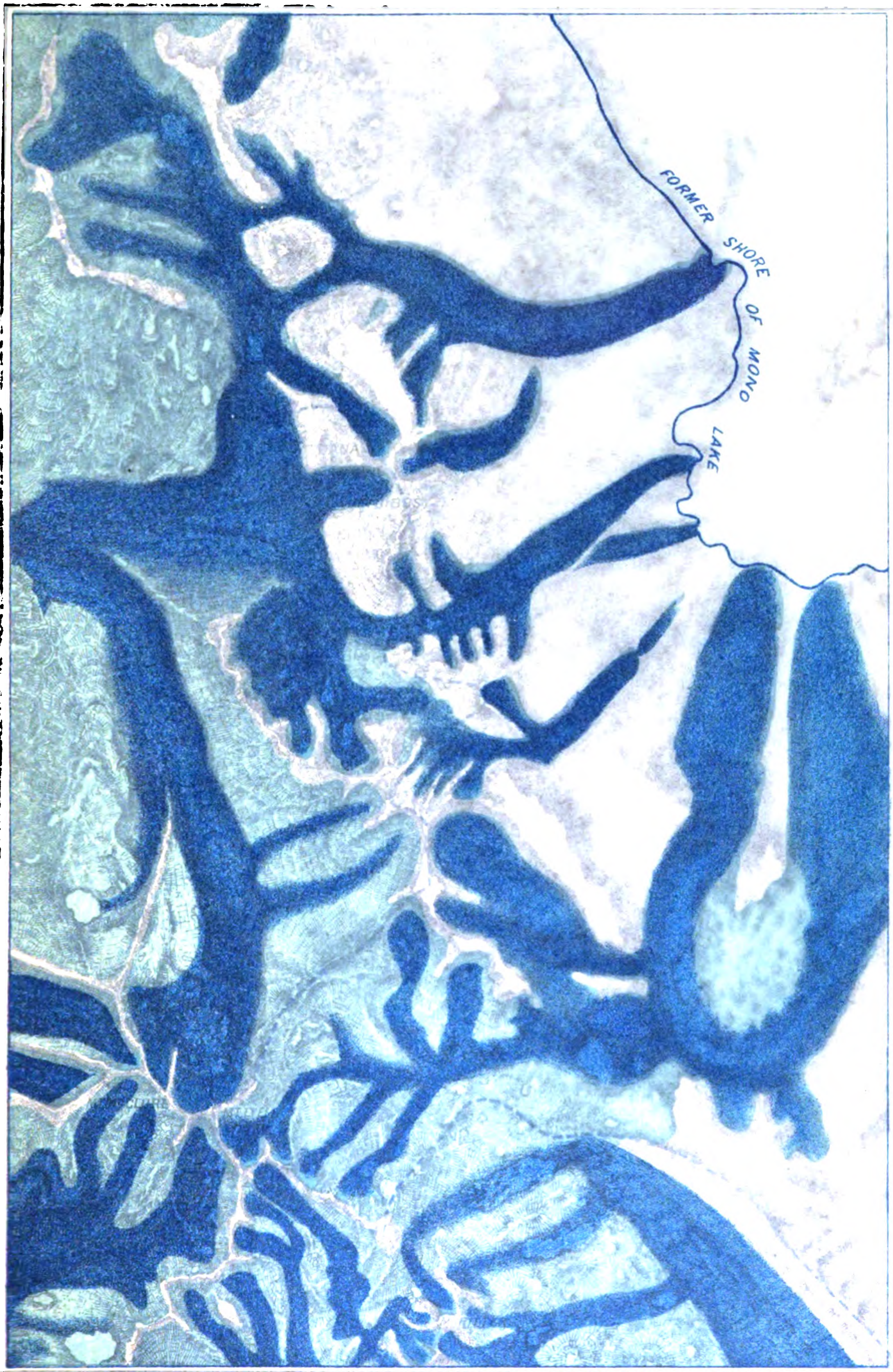
The glaciers with which we are most familiar belong to the class that have their archetype in the mountains of Switzerland, and occur about high peaks, usually in amphitheaters or *cirques* at the heads of high-grade valleys. The snow that accumulates on high mountains, especially in temperate latitudes, is frequently not completely melted during the summer, and thus tends to increase indefinitely. The *névé* of a glacier is such a snow-field. The gorge or valley leading from every alpine amphitheater furnishes an avenue of escape for the consolidated *névé*-snow, which is forced out through the opening, and flows for a greater or less distance as a stream of ice. Such in brief is the genesis

of an alpine glacier. Every glacier of this class is divided into a *névé*, or snow region, above and an icy portion below. The line of demarkation is the *snow-line*. As compact ice occurs also beneath the *névé* from which it is formed, this division of a glacier into two portions applies only to the surface. The division line, moreover, shifts with the seasons; at times, perhaps for many years together, the true glacier ice may be concealed by a snowy covering. The *névé* is composed of granular snow, white or grayish-white in color, and comparatively free from dirt and stones; below the snow-line the glacier is formed of both porous and compact ice, and is usually concealed more or less completely with rock débris. From a distance these two divisions are frequently distinctly shown by contrast in color. The stones and dirt that fall on the *névé* sink more or less deeply into the snow and become buried beneath the next addition, and as the *névé* becomes consolidated and acquires glacial motion, this débris is carried along in its mass. But the region below the *névé* being one in which loss exceeds supply, the snow and ice are melted, and the foreign bodies formerly held in the mass become concentrated at the surface, and are then carried along as moraines. Thus in the *névé* region the tendency is to bury foreign objects, and in the glacier proper to concentrate them at the surface.

All the débris carried by glaciers may be designated in general terms as *morainal* material, but when arranged in definite ways it receives specific names. When distributed along the margin of an ice-stream it forms *lateral* moraines. Two glaciers uniting, the right lateral moraine of one combines with the left lateral moraine of the other to form a *medial* moraine at the line of contact, the ice-streams flowing on side by side as a single compound glacier. The débris carried to the extremity of a glacier and deposited about its foot is known as a *terminal* or *frontal* moraine.

In flowing through a valley ice is subjected to stress, which causes it to fracture and form open fissures termed *crevasses*. When a glacier passes over a steep descent it becomes broken by a great number of fissures, and not infrequently falls to the base of an escarpment in detached blocks, forming an ice cascade, but heals its scars and flows on as a solid mass below. The fissures formed when a glacier passes over an inequality in its bed are commonly transverse to the direction of flow, but may take other courses, depending on the nature of the obstruction, change of slope, etc. Marginal crevasses, resulting from the friction of the ice-stream against its banks and the consequent more rapid flow of the central portion, usually leave the shore at a moderate angle and tend up-stream.

Glacier ice has been found to exhibit a definite structure, known as lamination, or as ribboned or banded structure, produced by the alternation of thin plates or strata of compact bluish ice with others more porous. As shown by Tyndall's experiments, this arrangement is the result of pressure, and is analogous to slaty cleavage.

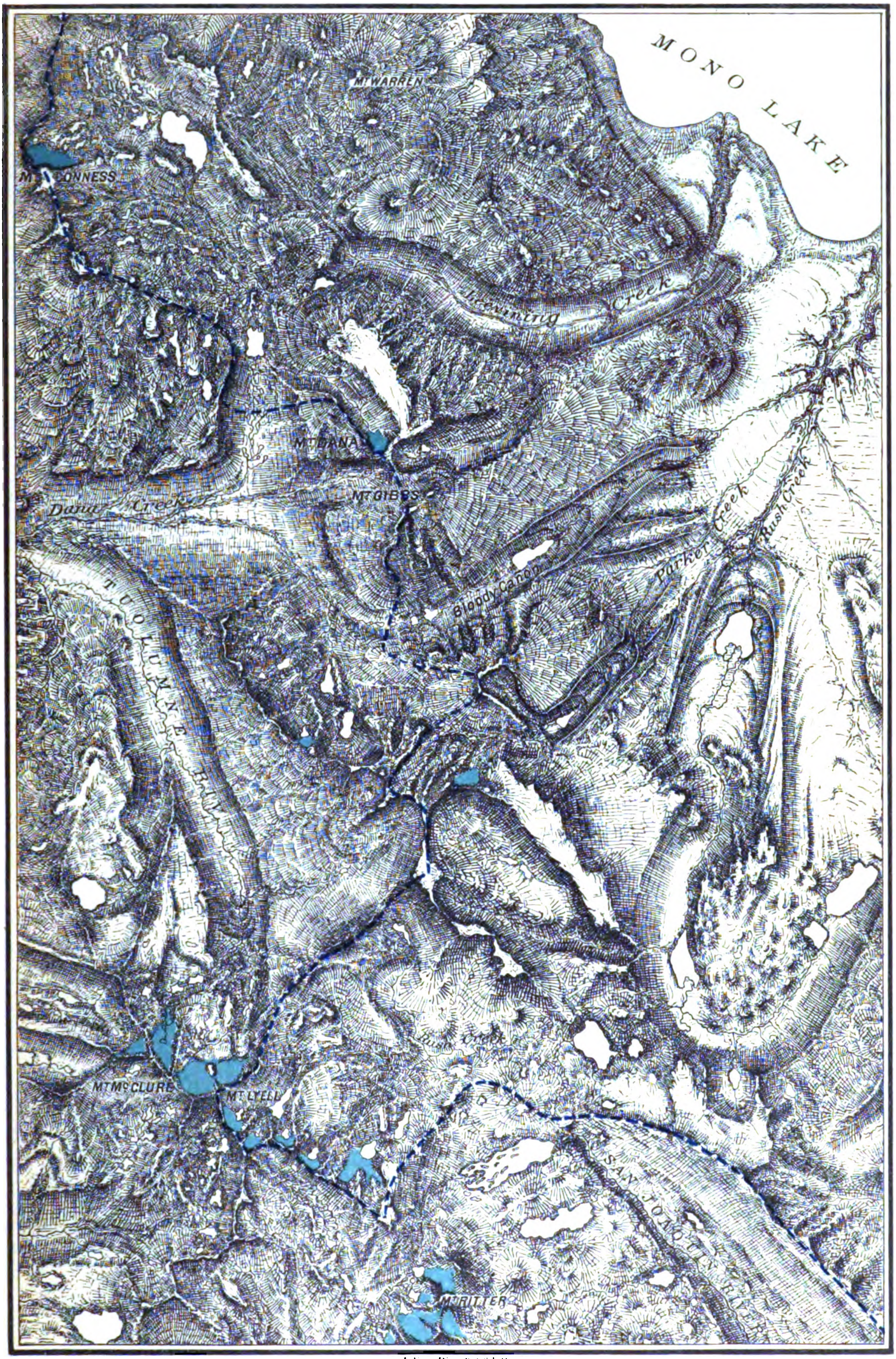


FORMER GLACIERS OF THE SIERRA NEVADA

Nevé Region

Glaciers

FORMER GLACIERS OF THE SIERRA NEVADA.



W. D. Johnson, Topographer Julius Bien & Co. Lith. I. C. Russell, Geologist.

EXISTING GLACIERS OF THE SIERRA NEVADA.

Glaciers ▬ Scale 1 inch = 2.5 Miles Pacific and Great Basin divide ‑ ‑

Scale of Miles

1 2 3 4 5 6 7 8

Owing to unequal melting, the surface of a glacier is usually extremely irregular, the parts protected by moraines standing in higher relief than the clearer portions. Still further diversity is formed by bowlders perched on columns of ice, which they have protected from melting as the general surface wasted away. These are termed *glacial tables*. At other times the ice bristles with a multitude of acicular pyramids, or is melted into holes and ice-wells, each having a stone or mass of dirt at the bottom.

The melting of the surface of a glacier gives rise to many rivulets and brooks, which course over it in channels of ice, frequently plunging into yawning crevasses, and finally joining the subglacial stream that issues from beneath every glacier. These glacier-born streams are always heavy with comminuted rock, ground fine by the moving ice.

Such in brief are the principal characteristics of alpine glaciers.

At the present time continental glaciers are confined to the arctic and antarctic regions, and have been less thoroughly explored than the alpine forms common in more temperate latitudes. Glaciers of this class are characterized by their broad extent and by not being confined by definite walls; their *névés* are large, frequently covering nearly the entire glacier, and their surfaces are free from bowlders and débris, for the reason that they are regions of accumulation, and also because mountains seldom rise above them. Owing to inequalities in the country over which these great fields pass, they are not infrequently broken by crevasses; and as on smaller glaciers the melting of the surface gives origin to numerous streams, frequently of large size, which become ponded and form lakes in basins of ice or plunge into open fissures and disappear in the body of the glacier. Existing continental glaciers are believed in all cases to flow from the interior towards the coast, and hence may be considered as acquiring motion in all directions from a center of accumulation. When alpine glaciers increase sufficiently to cover an entire mountain range and form a confluent ice-sheet, they approach and may pass into the continental type. It is not impossible that a mountain range of very modest dimensions might give origin to a quaquaversal glacier of vast proportions. It is perhaps not out of place to suggest in this connection that the glaciers which formerly covered the New England States and Canada were of this character.

In framing a definition of a glacier it is evident that we must include both alpine and continental types, and also embrace the secondary phenomena that are commonly present. A glacier is an ice-body originating from the consolidation of snow in regions where the secular accumulation exceeds the dissipation by melting and evaporation, *i. e.*, above the snow-line, and flowing to regions where loss exceeds supply, *i. e.*, below the snow-line. Accompanying these primary conditions many secondary phenomena, dependent upon environment, as crevasses, moraines, lamination, dirt-bands, glacier-tables, ice-pyramids, etc., may or may not be present. Thus, glaciers even of large size may exist

without moraines; in such an instance glacier-tables, ice-pyramids, ice-wells, etc., would be absent. We may conceive of a glacier flowing through a channel so even that it would not be broken by crevasses, but such instances must be extremely rare. The most common of the numerous secondary features seems to be the laminated structure of glacial ice, but even this is not always distinguishable in ice-bodies that are unquestionably true glaciers.

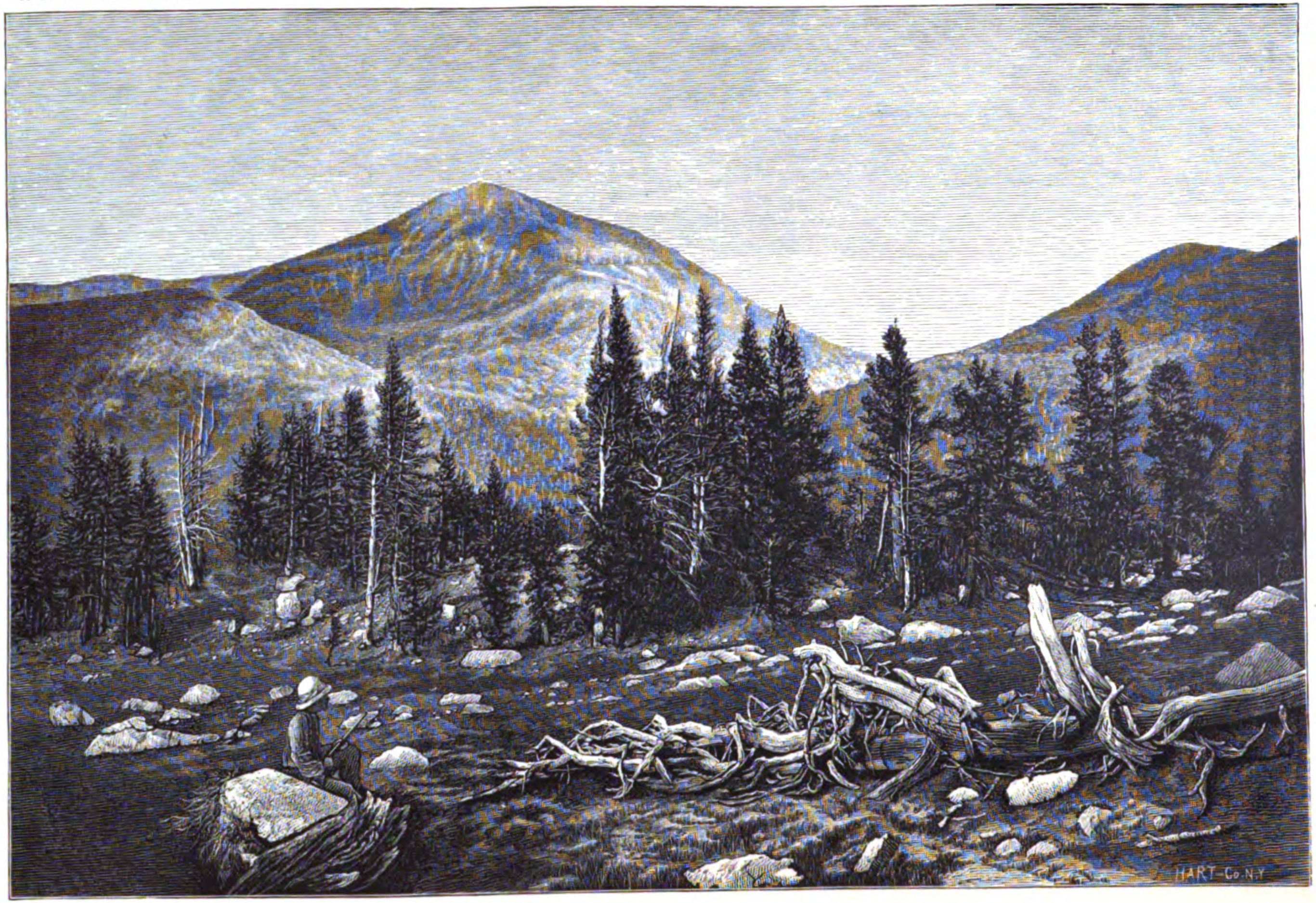
Although the definition we have presented may assist in understanding the nature of a glacier, yet it is manifestly open to objections. If we consider the snow-line as defining the limit between the *névé* and the glacier proper, it is evident that there must be numerous exceptions to the rule. As before remarked, during certain years, and in many instances for a term of years, the snow-line is much lower than at other times, and may completely conceal the glacier beneath. Again, an ice-stream may terminate in the sea and be broken up and form icebergs before the differentiation into *névé* and glacier proper has been reached.

From all that has been determined concerning the nature of glaciers it is evident that they form one of the transition stages in the history of the snow that falls in certain regions, and like genera and species in the organic kingdom cannot be limited by hard and fast lines, but may be classified by comparison with typical examples. From the snow, hail, and frozen mists of a mountain-top are formed the accumulations of granular ice-snow which we call a *névé*. By pressure and alternate melting and freezing, the *névé* passes into compact ice, which acquires motion and is termed a glacier; but the plane of separation is indefinite, and one merges into the other by insensible gradations.

A word in reference to the records inscribed by glaciers on the country they occupy, and we will pass to the immediate subject of our essay.

The morainal material carried by glaciers is deposited when melting takes place, and frequently forms characteristic accumulations that still retain the name of moraines. The débris along the border of an ice-stream is frequently left as ridges or irregular terraces on the sides of a valley, marking the former height of the ice flood. At various stages in the retreat of the ice the lateral moraines are united by terminal moraines, which cross the former bed of the glacier in irregular but usually crescent-shaped piles, between which the valley bottom is usually deeply filled with unassorted débris, and frequently occupied by lakelets. When a glacier is prolonged from the mouth of a valley on a plain, it builds out its lateral moraines perhaps for many miles, and when it retreats these are left as parallel embankments, not infrequently hundreds of feet high and sometimes miles in extent.

The movement of glaciers causes friction, which results, as the study of living glaciers has shown, in the smoothing and scratching of the rocks over which the ice passes. The bowlders, pebbles, and sand held in the bottom and sides of the glacier produce smoothed and polished surfaces, crossed by scratches and grooves having an exceedingly characteristic



MOUNT DANA FROM THE SOUTH.

appearance, which, when once understood, it is difficult to mistake for the results produced by other agencies. While the rocks beneath a glacier are being worn and rounded, the stones set in the ice are in turn battered and scratched and often ground down to plane surfaces that are not infrequently polished and covered with glacial striæ.

As a rule, alpine glaciers follow pre-existing drainage valleys, which they enlarge and broaden. As frequently stated, a stream-cut gorge is distinctly V-shaped, but after being occupied by a glacier it is found to have become U-shaped in cross-section.

The records of glacial action looked for by geologists are: deposits of morainal material, which frequently differs from the adjacent country rock, and may occur in an irregular manner or be grouped definitely as lateral and terminal moraines; bowlders perched in fortuitous positions, as on steep slopes and hill-tops; smoothly rounded rocky knolls; polished and scratched rock surfaces; rock-basins, etc.

With this elementary sketch to refresh the memory I propose to present in a somewhat popular form such observations as are attainable in reference to the existing glaciers of this country. In this connection, as the sequel will show, we have to deal solely with glaciers of the alpine type.

EXISTING GLACIERS OF THE SIERRA NEVADA.

The Sierra Nevada, by far the grandest of the mountain ranges of California, attains its greatest elevation between latitude 36° and 38° 30′, or, in a more general way, between Owen's Lake and Lake Tahoe.

To the more elevated region in this portion of the range the name of High Sierra was applied by the geologists of the California survey. Although the boundaries of the region thus designated are indefinite, it is well worthy of special distinction, as it is a prominent and important topographic feature. Throughout its entire extent it bristles with rugged peaks, narrow crests, and inaccessible cliffs overshadowing profound chasms, all of which combine to form one of the most rugged and picturesque mountain masses on the continent. The culminating point in this elevated region is near its southern limit, where Mount Whitney rises to an elevation of 14,448[1] feet above the sea and is succeeded as one goes northward by Mount King, Mount Humphreys, and many other mountain masses scarcely less magnificent. In the neighborhood of Mono Lake a number of the more prominent peaks, of which Mounts Lyell, Ritter, and Dana, and Tower peaks are examples, exceed 13,000 feet in elevation. Southward the Sierra declines rapidly, and the range is considered as terminating in that direction at Tehichipi Pass, a little north of latitude 35°. Northward of Mount Whitney there is a vast sea of rugged peaks and narrow mountain crests, separated by profound cañons, which render the region all but inaccessible to beings not equipped with wings. This is the High Sierra *par excellence*, as all will admit who have attempted to scale its dizzy peaks or thread its labyrinth of cañons. The range retains this rugged character all the way to Sonora Pass, and even to Lake Tahoe, but northward of that "Gem of the Sierra" the mountains are less elevated.

Very large portions of the High Sierra are composed of light-colored granite, which is commonly thinly clothed with vegetation, and imparts a cold gray tone to the rugged scenery. The peaks and crests overlooking Mono Lake, however, have been sculptured from somewhat metamorphosed sedimentary rocks, which have been penetrated by heavy beds of intrusive granite, and are frequently rich in color. The landscape in this portion of the range is in pleasing and striking contrast with the gray monotony of the western slope, and exhibits innumerable shades and tints which combine to form pictures as rich in tone as they are grand in proportions. The deep longitudinal valley lying in the

[1] Surveys West of 100th Meridian, Vol. II, p. 566.

MOUNT DANA FROM THE WEST.

crest of the range to the southward of Mount Dana is especially noteworthy for the beauty of its scenery, and deserves to be named in remembrance of some of the old Flemish masters, so deep and rich are its colors.

Besides the splendor of alpine scenery the mountains to the southward of Mono Lake present the additional attraction of living glaciers, which, although small, are well worthy the careful attention of every traveler.

PERSONAL OBSERVATIONS.

Existing glaciers on Mount Dana and Mount Lyell were visited by Mr. G. K. Gilbert and myself during the summer of 1883; I also examined one at the head of Parker Creek, a tributary of Mono Lake; others on Mounts Conness, McClure, and Ritter were explored by Mr. Willard D. Johnson, my companion and assistant, while making a topographical survey of the region draining into Mono Lake. Besides the glaciers actually examined, a number of others were seen from commanding points and their general nature was as thoroughly understood as if their surfaces had actually been trodden. Our combined observations have shown that nine glaciers now exist within the southern rim of the Mono Lake drainage basin; while a somewhat larger number are to be found among the mountains of which McClure, Lyell, and Ritter are the dominant peaks, and from which flow the Tuolumne, Merced, and San Joaquin Rivers.

The glaciers of the High Sierra are located between latitudes 36½° and 38°, and have an approximate elevation of 11,500 feet above the sea. The lowest seen was on the northern side of Mount Ritter, and terminates in a lakelet that is about 2,000 feet below the mountain top, or approximately 11,000 feet above the sea. The glaciers observed are all small, the most extensive—that on the northern slope of Mount Lyell—being less than a mile in length, with a somewhat greater breadth. Nearly all occur in amphitheaters or *cirques* on the northern sides of lofty peaks, where they are sheltered by high cliffs and mountain ridges, and all flow northward, excepting a few seen in deep *cirques* on the eastern side of the Minarets and Mount Ritter; so far as known these are the most southerly of any in the United States. Snow-fields are reported by Mr. Johnson, however, as existing in the mountains to the southward of Mount Ritter, at the head of some of the many branches of Owen's River. If these prove to be veritable glaciers they will extend the southern limit of the existing glaciers of this country, a few miles farther southward.

MOUNT DANA GLACIER.

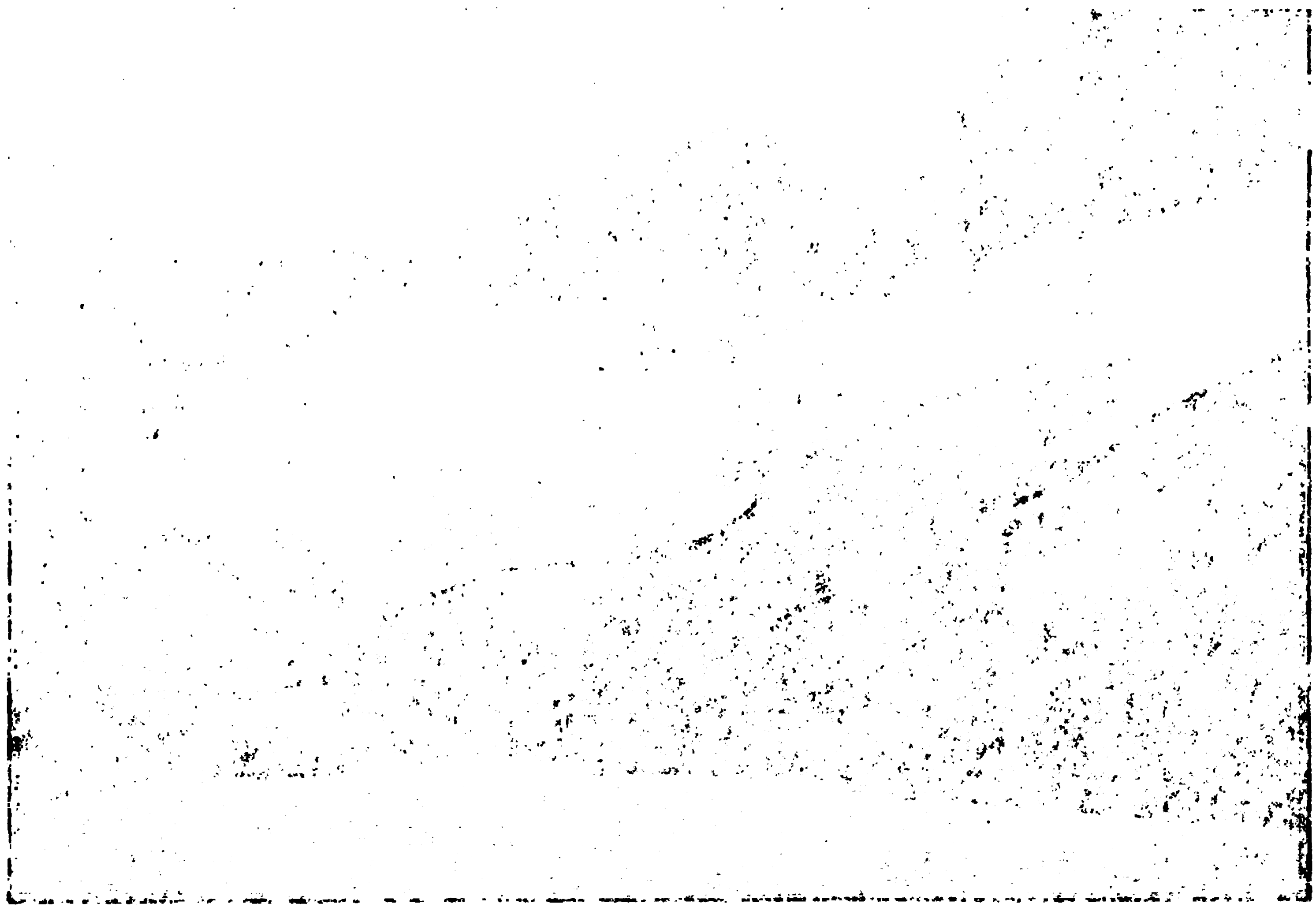
On the western shore of Mono Lake the mountains rise abruptly from the water's edge to an elevation of 5,000 or 6,000 feet, and have been sculptured by storm and frost into many independent peaks of remark-

able grandeur. As seen from Mono Lake, the most conspicuous point along the mountain crest is Mount Dana, which rises 6,500 feet above the lake and has an elevation of 13,227 feet above the sea.[2] Although of grand proportions, the peak is but one among many which form the crowning points on the divide separating the drainage of Mono Lake from that of the Pacific. From the southward Mount Dana presents a somewhat rounded contour, as shown in Plate XXXIII, and is easy of ascent; on the north, however—as may be judged from Plate XXXIV, which shows it in profile, the view being eastward from the divide between the mining camps of Tioga and Lundy—it forms a nearly perpendicular face more than a thousand feet high. This northern face descends into a deep narrow cañon leading northward, which we have named Glacier Cañon. In the illustration forming Plate XXXIV a partial view of this gorge is obtained, as well as a glimpse of the *névé* of the Dana Glacier which occurs at its head. During the Glacial epoch the whole extent of this cañon was occupied with ice, which formed a tributary of the ancient Leevining Creek Glacier and flowed into the Mono Lake basin. The valley formerly occupied in part by this glacier is seen in the foreground of the illustration. In Plate XXXV a general view of nearly the entire Dana Glacier is presented as seen from the moraine at the lower side of the lake of milky opalescent water that lies at its foot. The moraine now forming can be seen curving about the end of the glacier, while small crevasses are observable at the right. The glacier is perhaps 2,000 feet long in the direction of the flow, but appears much foreshortened in the illustration. "Ice tongues" are seen extending upward from the *névé*. At the base of the largest of these a portion of a wide crevasse is visible. Plate XXXVI is a nearer view of the same glacier, in which the minor features are more clėary defined. Plate XXXVII exhibits the end of the glacier, and shows the extremely rugged nature of the ice surface; narrow dirt bands, sweeping in undulations across the terminus, are also visible.

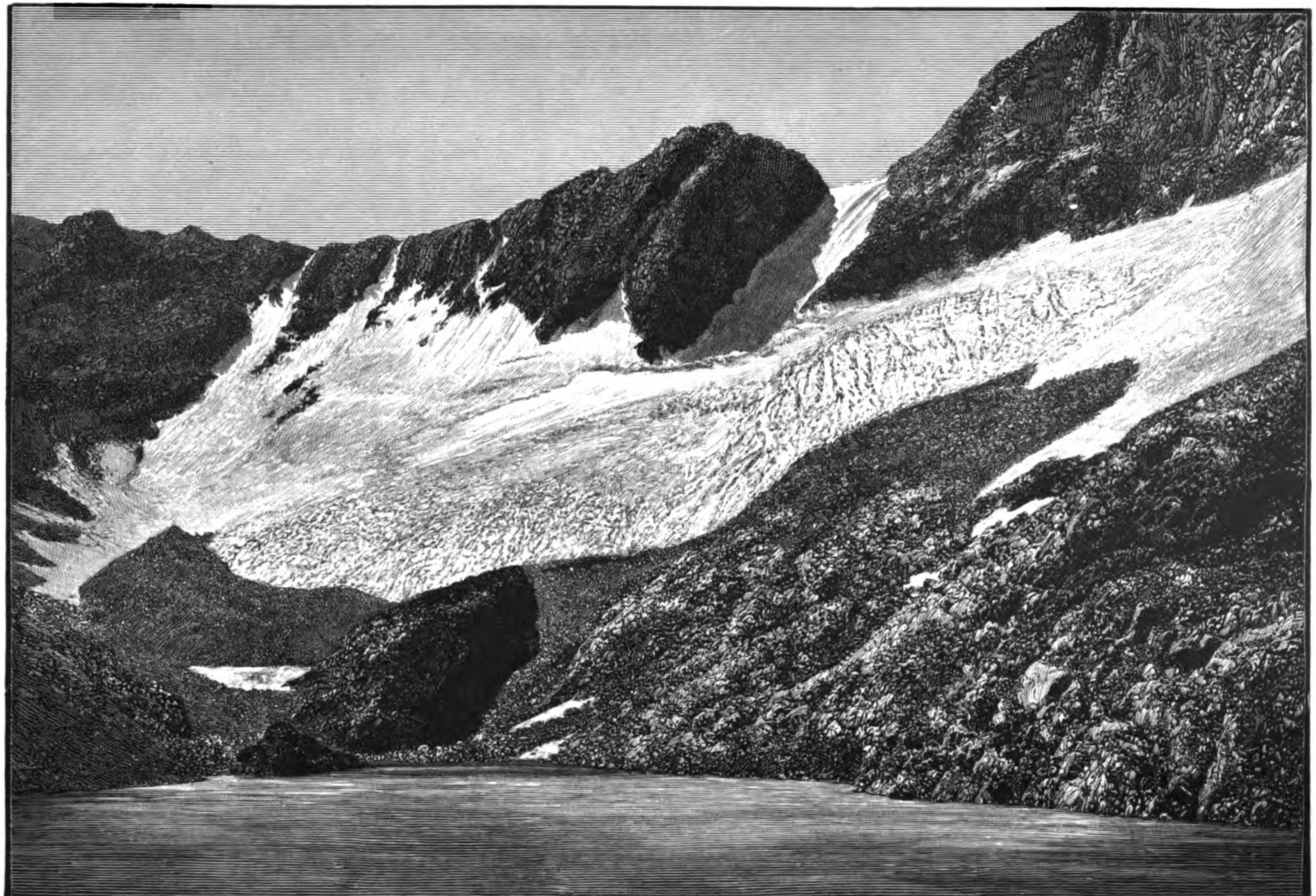
MOUNT LYELL GLACIER.

In traveling from Mount Dana to Mount Lyell one finds it most convenient to pass down Dana Creek to its confluence with the Tuolumne, and then ascend the deep broad-bottom cañon of the latter stream, which leads directly to the Lyell Glacier, at the foot of which the river has its birth. Plate XXXVIII presents a view of the snowy summit of Mount Lyell as seen from near the head of the Tuolumne Cañon. The majestic mountain as seen from this portion of the valley is far more grand and beautiful than any illustration in black and white can suggest. In the soft gray light of morning it has all the solemn grandeur of the Bernese Oberland, and at sunset, when flushed with the rosy light of the afterglow, this shrine of the High Sierra rivals the splendor of Mount Rosa. To the right of Mount Lyell rises Mount McClure,

[2] Elevation of Mono Lake determined from railroad levels; height of adjacent peaks measured by angulation.



MOUNT DANA GLACIER.



MOUNT DANA GLACIER

which is scarcely less grand than its companion; the former attains the height of 13,217 feet above the sea and the latter is 150 feet less in elevation.

The Tuolumne Cañon, when followed still nearer to its beginning, is found to lose its gentle grade and become rugged and precipitous, being crossed at intervals by irregular cliffs, that must have caused magnificent ice-cascades in the great glacier that once flowed over them. The top of each steep ascent is usually separated from the base of the next higher one by a comparatively level tract, sometimes holding a swampy meadow. This succession of cliffs and terraces forms a grand stairway, leading up to the opening of the amphitheater on the northern side of Mount Lyell, whence a magnificent panorama of the entire glacier may be obtained. The view given on Plate XXXIX is from near the outlet of the amphitheater, and will assist in interpreting the map of the Lyell Glacier given on Plate XL. In the panorama the moraine now forming at the foot of the glacier is well shown, as is also the rounded rock-mass that rises as an island in the central portion of the glacier; the crevasses and contorted dirt-bands at the foot of the ice, although noticeable features when seen in nature, are but indifferently represented in the illustration. A view down the cañon of the Tuolumne is presented on Plate XLI, as an illustration of the height on a side of the valley attained by the ancient glacier; by estimate the terrace marking the upper limit of the ice river is about 2,500 feet above the present bed of the Tuolumne.

PARKER CREEK GLACIER.

This glacier is situated at the head of the deep, high-grade cañon through which Parker Creek descends to the valley of Mono Lake. It is smaller than the ice-bodies on Mount Dana and Mount Lyell, but is yet a true glacier ,with a well-defined *névé* region, from beneath which descends a mass of ice that is crossed by dirt-bands and crevasses, and has many of the minor features characteristic of glaciers. About the foot of the ice there are huge moraines, forming concentric ridges, which in mass must far exceed that of the glacier as it exists at the present time. These moraines are more characteristic examples of the tumultuous débris piles formed by ice-action than any other recent deposits of the same nature seen in the High Sierra. Like the majority of the glaciers in this region, the one at the head of Parker Creek is sheltered by the walls of an amphitheater, and flows northward. During the Glacial epoch the entire extent of Parker Creek Cañon was occupied by a glacier which descended upon the Mono plain and built huge embankments more than a mile in length, which are only second in interest to the similar deposits at the mouth of Bloody Cañon.

GLACIAL PHENOMENA.

That the ice-bodies observed in the High Sierra, although small, are yet veritable glaciers, I trust will appear from the following somewhat detailed statement of observations.

Névé and glacier.—The distinction between *névé* and true glacier ice is plainly manifest in the Sierra Nevada glaciers, not only when viewing them from a distance, but also while traversing their surfaces. In the case of the Parker Creek Glacier especially, the change from the granular snow of the *névé* to the compact ice of the glacier can be discerned within the space of a very few feet.

The *névé* is invariably white as compared with the rest of the glacier, and is composed of granular ice-snow. Its surface is almost entirely free from stones and dirt, and is rendered very rough and uneven by crests and spires of ice from 2 to 5 feet high that result from the unequal melting of the surface. These "ice-blades" have been described by Le Conte,[3] who refers their origin to the unequal melting of wind-rippled snow.

At its lower limit the *névé* passes into the glacier proper—which in part it overlies—and acquires a ribboned or laminated structure, dirt-bands, etc., characteristic of a true glacier. A protrusion of compact ice below the *névé* was observed in all the glaciers seen in the High Sierra.

Crevasses.—Marginal crevasses were observed in numerous instances, but they occur in quite limited numbers in any individual glacier. In some examples the marginal crevasses in the *névé* region were convex toward the head of the glacier, while others farther down in the same series had become straight, or had changed their curvature so as to be concave upward. A series of crevasses illustrating this change is shown in the central portion of the map of the Lyell Glacier, forming Plate XL. The crevasses seen most commonly occur near the head of the *névé* and correspond to the "bergschrund" of Swiss mountaineers. These vary from narrow cracks up to chasms 6 or 8 feet wide, which frequently cross almost the entire breadth of the *névé* and often render the passage to the rocks above extremely difficult. The depth of the crevasses could seldom be determined, the irregularities of their sides limiting the view; but some were certainly not less than 100 feet deep. The crevasses at the head of the *névé* were frequently arched with snow and hung within with vast numbers of smooth icicles. The walls beneath these treacherous roofs were incrusted with large masses of well-formed *ice-crystals*, which exhibited flashing faces half an inch in diameter and resembled the most beautiful transparent spar. The light in these fairy-like grottoes was of the most exquisite blue.

Lamination or ribboned structure.—This structure was seen in all the glaciers closely examined, but appeared most conspicuously near the lower extremity of the ice, where the lamination was approximately horizontal. Hand specimens cut from the ice exhibited sections of alternating narrow bands of compact blue ice and porous white ice as plainly as could be desired.

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[3] Postea, page 325.

... distinction between *névé* and true glacier ice is ... Sierra Nevada glaciers, not only when viewing ... traversing their surfaces. In the ... the change from the granular ... compact ice of the glacier can be discerned ... few feet.

... as compared with the rest of the glacier, ... Its surface is almost entirely ... rendered very rough and uneven by ... from 2 to 5 feet high that result from the ... surface. These ice blades have been described ... their origin to the unequal melting of wind ...

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* ... page 326.

MOUNT DANA GLACIER.

Dirt-bands.—These were observed on nearly all the glaciers, and were frequently a marked and even a conspicuous feature of their surfaces. It required no peculiar condition of light and shade to make them discernible; on the contrary, they could be plainly distinguished at a distance of 2 or 3 miles. Viewed from a distance they were seen to sweep entirely across the glacier in a series of graceful curves concaved towards the *névé*. Sometimes their symmetry was interrupted by irregular undulations, or even by contortions, as may be seen at the foot of the Lyell Glacier. On the Parker Creek Glacier the dirt-bands are about 6 inches broad over a considerable area, and occur at quite regular intervals of from 4 to 6 feet, with comparatively clean ice between. In this instance the dirt producing the bands was not confined to the surface, but could be seen to discolor the ice in quite a well-defined stratum, dipping into the glacier at a low angle. On all the glaciers examined the dirt-bands were observed only below the lower limit of the *névé*.

In the study of the glaciers of Switzerland and Norway particular attention has been given to the influences of ice-cascades in producing laminated structure and dirt-bands. In the Sierra Nevada glaciers, both of these characters are distinct and well marked, but ice-cascades are absent. It seems evident, therefore, that the hypothesis which is apparently satisfactory in Europe will not account for the phenomena to be seen in California.

In viewing many of the Sierra Nevada glaciers from a distance of a few miles, and approximately at the same level, it is apparent that their surfaces, frequently having a slope of from 15° to more than 30°, are in reality sections of the ice-body, and therefore expose its internal structure. When seen in this manner the appearance of the glaciers is such as to lead one to suspect that the dirt-bands are strata in the ice, or in reality "annual rings" formed by annual accumulations of dirt in the *névé*, as long since suggested by Forbes[4] in explanation of the similar bands observed on the Swiss glacier. It is pertinently suggested by Prof. W. H. Brewer that a year of exceptional melting—one of those years which reduce the *névé* to its minimum—would have the effect of combining the dirt accumulated during several years into a single band. A single dirt-band may thus represent a climatic cycle longer than a single year.

Glacier-tables.—Blocks of stone perched on columns of ice, termed "glacier-tables," did not, in 1883, form a marked feature in the glacier surfaces, except in the case of the Parker Creek Glacier. There they were numerous, and in all stages of growth and decadence. Some of the blocks were poised horizontally on their pedestals; others were inclined southward, or had been partially dislodged; again they had fallen and were lying on the southern side of the pinnacles which had

[4] Prof. J. D. Forbes, Travels through the Alps of Savoy, p. 408.

formerly supported them. Sketches made on the Parker Creek Glacier of a few of these perched stones have been grouped in the following figure.

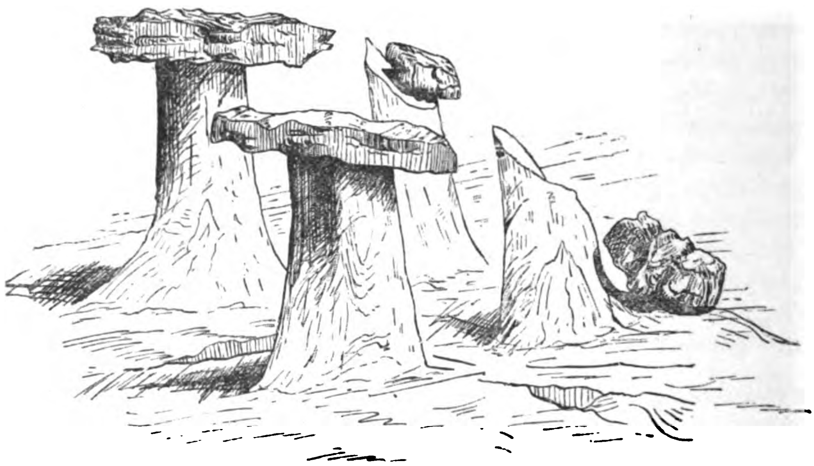
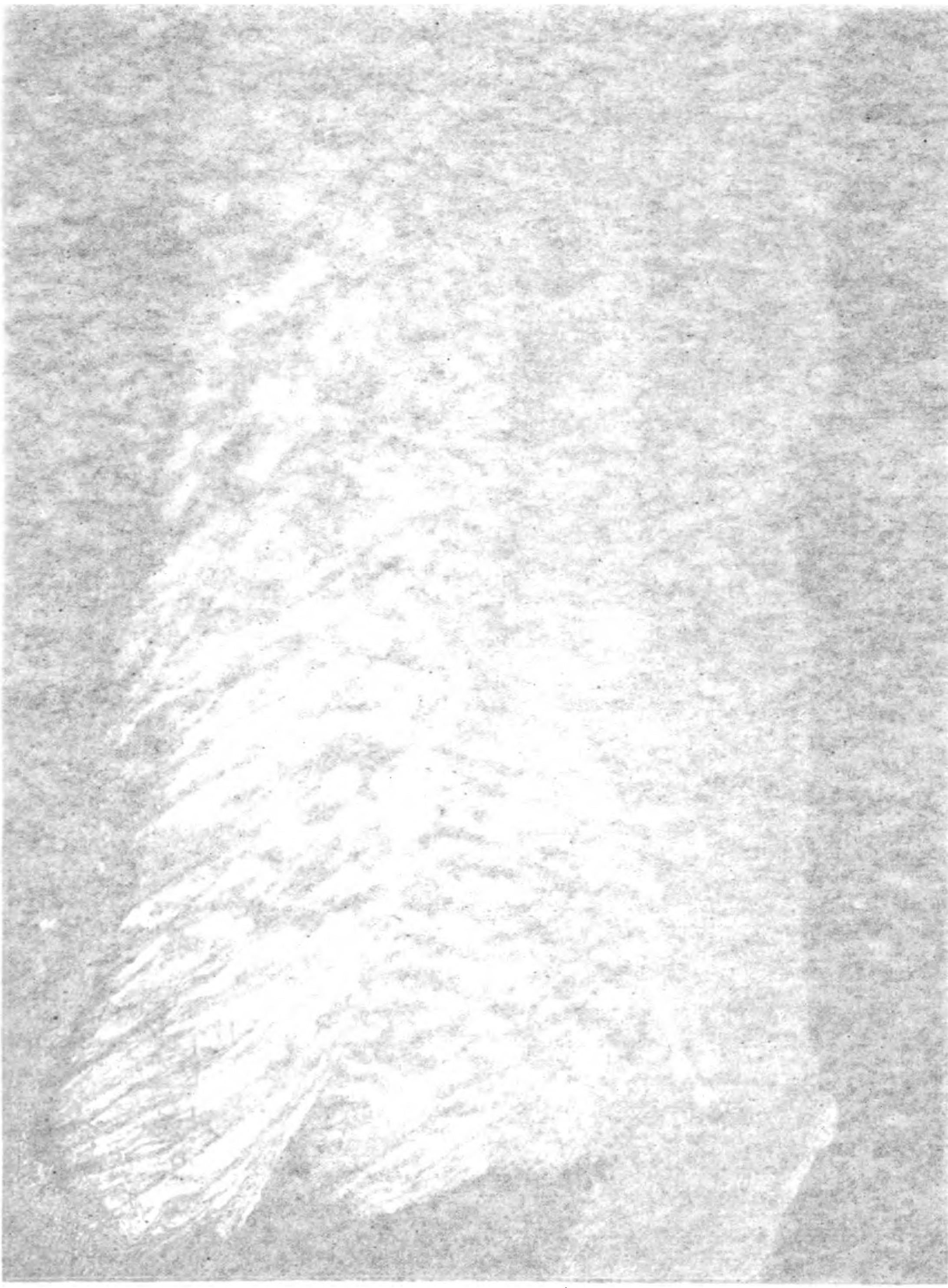


FIG. 138.—Glacier Tables, Parker Creek Glacier.

The largest glacier-table observed was near the center of the Parker Creek Glacier, a few hundred feet from its terminus. This was a block of dense volcanic rock measuring 34 by 23 by 10 feet, supported by a column of ice 8 feet high on its northern and 6 feet high on its southern side, with a thickness of 6 or 8 feet. The smallest blocks that are able to protect the ice beneath sufficiently to form columns as the general surface melts away were found to be about 16 by 10 by 10 inches; when smaller than this they sink into the surface in a manner that has been graphically described by Tyndall and others. Small pebbles were frequently seen at the bottom of little ice-wells 5 or 6 inches deep. Good examples of the "sand-cones" seen so frequently in the Swiss glaciers were not observed.

Ice-pyramids.—As the forms we have included under this name furnish a detail of glacier surface that has not previously attracted our attention and which apparently has not been described by glacialists, we shall transcribe our notes concerning them at some length.

On the lower portion of the Lyell Glacier, more than in any other instance, the surface bristles over a large area with acute pyramids of ice from a few inches to fully 3 feet in height with moderately small bases. At the northern base of each pyramid there invariably is a stone—sometimes measuring 5 or 6 inches in diameter—or a number of loose pebbles or a handful of dirt, which is usually depressed somewhat below the general surface of the glacier. The side of the pyramid rising above the stone, *i. e.*, the northern face, is usually concave and invariably composed of compact ice, while the remainder of the structure



FOOT OF MOUNT DANA GLACIER.

is of the ordinary porous ice forming the glacier surface. Sometimes the nearly horizontal lamination of the glacier-ice can be seen in the southern face of the pyramids. A direct relation is noticeable, too, between the size and shape of the pebble and the height and form of the ice-pyramid that rises above it.

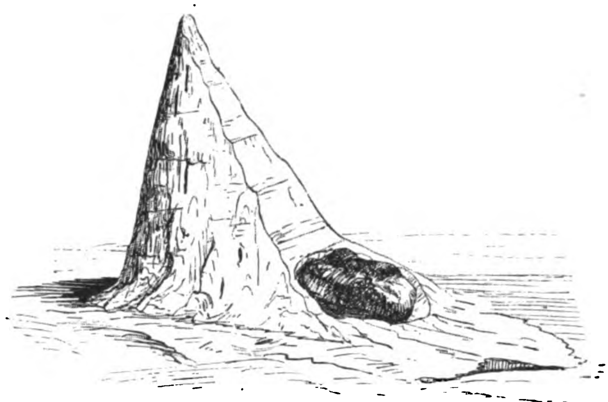


FIG. 139.—Ice-Pyramid on Mount Lyell Glacier.

In seeking an explanation of these phenomena the only hypothesis that seems to satisfy the facts observed assumes that a small stone or mass of dirt lying on the surface of a glacier becomes heated and melts the porous ice beneath, and that the water thus formed freezes again into *compact* ice, which resists the sun's heat more effectually than the surrounding *porous* ice and hence is left as the general surface melts away. In nearly every instance the stone at the base of the pyramid had been carried northward as it melted its way downward, thus forming the steep northern slope of the pyramid, and at the same time tending to prevent the formation of a pyramid on the northern side of a sunken block. The pyramids always point toward the noonday sun, hence the compact ice formed on the northern side of a block is more exposed than that on the southern side, and is therefore more rapidly melted away.

Moraines.—No well-marked medial moraines were noticed on any of the Sierra Nevada glaciers, as they are all simple ice-streams without tributaries. Lateral moraines resting on the ice at the margins of the glaciers were seen in many instances and could be traced to the cliffs from which they originated. Terminal moraines, however, are common; they occur at the lower limit of every glacier observed, and are remarkable for their size when compared with the extent of the parent ice-stream. It is difficult to measure these irregular crescent-shaped heaps with accuracy, owing to the uncertainty of their depth and the manner

in which they merge with one another. It is also frequently impossible to determine whether or not they rest on an extension of the glacial ice.

The terminal moraine now forming at the lower extremity of the Dana Glacier is approximately 1,000 feet long by 30 or 40 feet broad and possibly 100 feet deep. Below this, and united with it, is a second of somewhat greater dimensions, which is followed by other similar crescent-shaped heaps of débris. The corresponding moraines at the extremity of the Lyell Glacier are considerably larger, as are also the still more typical terminals at the foot of the Parker Creek Glacier. In some instances these moraines were coated with loose rubbish and dirt that would be swept away by a single storm, indicating that they had received their latest additions within a very few months.

The bottom of the Dana Glacier was seen to be heavily charged with stones, pebbles, and sand, and to rest on a bed of bowlders of considerable thickness. This may be called a "ground moraine."

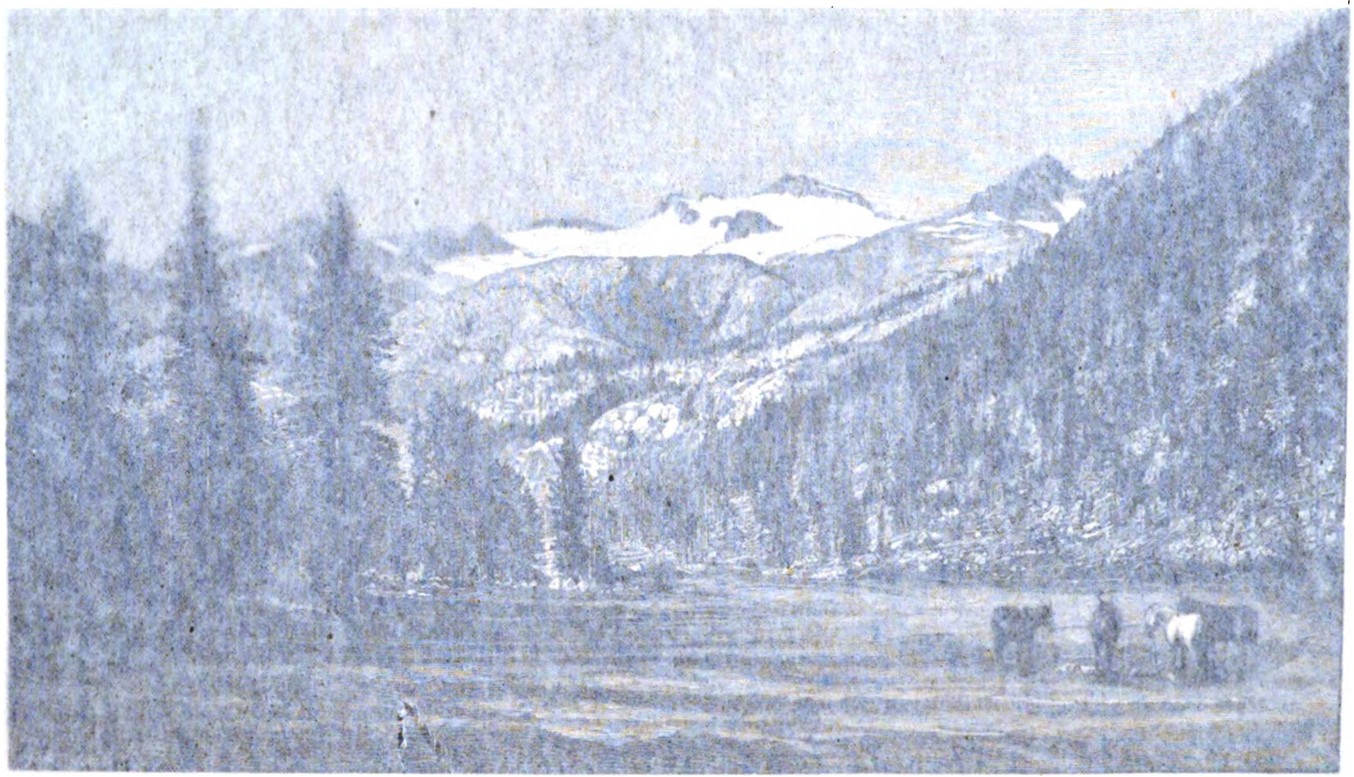
Glaciated surfaces and scratched stones.—The rock surfaces in the immediate neighborhood of the glaciers are frequently polished and covered with a net-work of grooves and scratches, but it is usually impossible to determine whether this has been the work of the existing ice-streams or whether it is a part of the vast glaciation imposed upon all of the High Sierra during the Glacial epoch. In some instances, however, there is no doubt that the markings were made during the past few years.

At the immediate foot of the Dana Glacier we found a number of stones that were battered and worn and exhibited planed and scratched surfaces, in many respects similar to the glaciated stones found in the ancient moraines of New England. These occurred but a few feet from the ice-foot, and their bruises and scratches were, without question, the work of the present glacier.

Glacier movements.—Measurement of the motions of the glaciers was not undertaken, but their movement is apparent both from the nature of the crevasses and the curved course of the dirt-bands that cross them. The rate of the flow of a glacier on Mount McClure, however, was determined more than ten years since by Mr. John Muir, who found its maximum movement near the center to be 47 inches in forty-six days (from August 21 to October 6, 1872).[5]

Glacier mud.—The Tuolumne River has its source at the foot of the Lyell Glacier; at its birth it is a rivulet, turbid with silt that has been ground fine by the moving ice from beneath which it issues. At the foot of the Dana Glacier there is a small lakelet confined in a rock-basin, which acquires a peculiar greenish-yellow color from the silt held in suspension. The water escapes from this lake through an ancient moraine piled on the rim of the basin, and is gathered in other depressions farther down the cañon, forming lakelets that are wonderfully clear and blue, like the hundreds of sister lakes scattered throughout the surrounding glaciated area. The sediment from the glacial streams

[5] Postea, p. 324.



MO[illegible] FROM THE TUOLUMNE VALLEY.

that they merge with one another. It is also frequently impossible to determine whether or not they rest on an extension of the glacial ice.

The terminal moraine now forming at the lower extremity of Dana Glacier is approximately 1,000 feet long by 30 or 40 feet broad and possibly 100 feet deep. Below this, and united with it, is a second crescent of somewhat greater dimensions, which is followed by other similar crescent-shaped heaps of debris. The corresponding moraines at the extremity of the Lyell Glacier are considerably larger, as are also the similar crescent-shaped terminal moraines at the foot of the Parker Creek Glacier. In some instances these moraines were covered with loose rubbish and dirt that could be swept away by a single storm, indicating that they had received their last additions within a very few months.

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*Postea, p. 394.

MOUNT LYELL FROM THE TUOLUMNE VALLEY.

MOUNT LYELL GLACIER.

was found to [illegible] in tall [illegible] [illegible] whe[illegible] once [illegible]

[illegible] In the deep [illegible] of the glaciers [illegible] are [illegible] the higher p[illegible]. [illegible] which shoots up above the [illegible] feet in height, and also [illegible] or descend them [illegible] cutting steps. [illegible] feature of the [illegible] the [illegible] of W[illegible] whether they [illegible] remain to be determined.

Red snow.—While Mr. Gilbert and myself [illegible] portion of the Lyell Glacier, we [illegible] and a b[illegible] at pinkish tint [illegible] undisturbed [illegible] heaps, grayish white. [illegible] the lower border [illegible] more distinct [illegible] in some instances the borders of rills were [illegible] the "red snow" was superficial. [illegible] was examined with a microscope [illegible] to consist of deep red globules from 150 to [illegible] which [illegible] determined to be the [illegible]

The [illegible] of the glacier.—Our examination [illegible] [illegible] since sunrise, w[illegible] in which the [illegible] mountain tops. As the sun rose above the [illegible] and flushed the snow-fields with a [illegible] light [illegible] [illegible] here on the glacier, gradually [illegible] [illegible] increased. [illegible] rest[illegible] down the [illegible] ice, sometimes [illegible] being lost to view. At mid[illegible] everywhere over the glacier, but as the chill of evening [illegible] [illegible] gradually [illegible] [illegible] over the frozen regions.

[illegible] that this [illegible] melting has [illegible] which the glacier has received [illegible] accounts we have of the [illegible] of the High Sierra. The glaciers of [illegible] are p[illegible] subject to periodic [illegible] [illegible], and are evidently not [illegible] at the present time.

[illegible] J. D. Whitney, [illegible] account of an ascent of [illegible] Shasta [illegible] vol. I, p. [illegible] the occurrence of "red snow" over a very considerable [illegible] from 8,0[illegible] to 12,0[illegible] feet, and [illegible] [illegible]

[illegible] pp. 324-[illegible]

was found to be an impalpable mud, so extremely fine that it requirde a long time to settle when once diffused through water.

Ice-tongues.—In the steep amphitheater walls overlooking the *névés* of the glaciers there are frequently deep, narrow cliffs leading towards the higher peaks. In many instances these are partially filled with ice, which shoots up above the *névés* in tapering tongues some hundreds of feet in height, and at so high an angle that it is impossible to ascend or descend them without cutting steps. These "ice-tongues" are an interesting feature of the Sierra glaciers, and appear also at the head of the ice-streams of Wyoming; whether they have glacial motion or not remains to be determined.

Red snow.—While Mr. Gilbert and myself were examining the *névé* portion of the Lyell Glacier, we noticed that our foot-prints in the snow had a bright pinkish tint, the undisturbed surface appearing white or, perhaps, grayish white. At the lower border of the *névé* the color becomes more distinct and could be plainly seen in the untrodden surface, and in some instances the borders of rills were brightly stained. In all cases the "red snow" was superficial. Some of the coloring matter collected was examined with a microscope a number of months after and found to consist of deep red globules from 150 to 200 millimeters in diameter, which were determined to be the still form of *Protococcus*.[6]

The melting of the glaciers.—Our examination of the Lyell Glacier began one August morning before sunrise, when the vast amphitheater in which the ice is cradled was hushed in the profound stillness peculiar to mountain-tops. As the sun rose above the granite spires to the eastward and flushed the snow-fields with a ruddy light, little rills started here and there on the glacier, gradually gathering strength as the sun's warmth increased. By noon brooks of considerable size were rushing down channels of ice, sometimes plunging into crevasses and becoming lost to view. At midday the murmur of water was heard everywhere over the glacier, but as the chill of evening came on, the music of the streams gradually ceased, and by sunset the stillness of death again reigned over the frozen regions.

That this noonday melting has more than counterbalanced the annual additions which the glacier has received during the past few years, seems evident from the accounts we have of the previous extent of the snow-fields of the High Sierra.[7] The glaciers of California, like those of Switzerland, are probably subject to periodic changes due to climatic oscillations, and are evidently not increasing at the present time.

[6] Prof. J. D. Whitney, in an account of an ascent of Mount Shasta—Geology of California, Vol. I, p. 338—mentions the occurrence of "red snow" over a very considerable area at an elevation of from 8,000 to 12,000 feet, and ascribes its color to the presence of *Protococcus nivalis*.

[7] Postea, pp. 324–326.

PREVIOUS EXPLORATIONS.

Although giving precedence to my own observations in describing the glaciers of the High Sierra, I do not wish to ignore the reports of those who have preceded me. The anonymous article on the "Living Glaciers of California"[8] which appeared in the Overland Monthly for December, 1872, we have already referred to as being from the pen of Mr. John Muir, and is, so far as known, the first announcement of the existence of glaciers in the Sierra Nevada. Mr. Muir states that in October, 1871, he was among the mountains of the "Merced group" and found a living glacier, with very recent moraines at its foot, from beneath which issued a stream charged with fine mud; further observation revealed dirt-bands, crevasses, and lateral moraines, thus leaving no doubt that the "snow-bank," as it had previously been considered, was an actual glacier. Other similar ice-bodies were examined by Mr. Muir on Mount Lyell and Mount McClure; and from the top of Mount Lyell he saw a dozen small glaciers on neighboring peaks.

In August, 1872, Mr. Muir placed five stakes in the glacier on Mount McClure for the purpose of demonstrating that it had true "glacial motion." Four of these were ranged in line from the east side to a point near the middle of the glacier, the first being 25 yards from the east bank; the second, 94; the third, 152; and the fourth, 225 yards. On observing the stakes on October 6, forty-six days after being placed in position, it was found that No. 1 had been carried down the glacier 11 inches; No. 2, 18 inches; No. 3, 34 inches; No. 4, 47 inches. Stake No. 4 was near the middle of the glacier and was thought to represent the maximum motion. Stake No. 5 was placed about midway between the head of the glacier and stake No. 4; its motion was 40 inches in 46 days. These measurements, although not as detailed and perhaps not as accurate as could be desired, are yet sufficient to demonstrate, as claimed by Mr. Muir, that the ice in this instance has true glacial motion. In this example, as in all normal glaciers, the most rapid movement was near the middle of the ice-stream.[9]

The Mount McClure Glacier, when visited by Mr. Muir, was approximately half a mile long, and of about the same breadth in the widest part, and was observed to be traversed in the southeast corner by crevasses several hundred yards long but only about a foot wide. The Mount Lyell Glacier, in 1872, is stated to have been about a mile in length by a mile in breadth.

Mr. Muir also describes narrow high-grade cañons called "devil's slide," "devil's lanes," etc., which occur about the higher peaks and are frequently occupied by ice. In one of these gorges the ice was found

[8] Reprinted in the American Journal of Science, Vol. V, Third series, 1873, p. 69.

[9] Motion in the Lyell Glacier is also referred to by Salem Clarke. Proceedings of the Boston Society of Nat. Hist., Vol. XV, 1873, p. 259.

[illegible] EXPLORATIONS.

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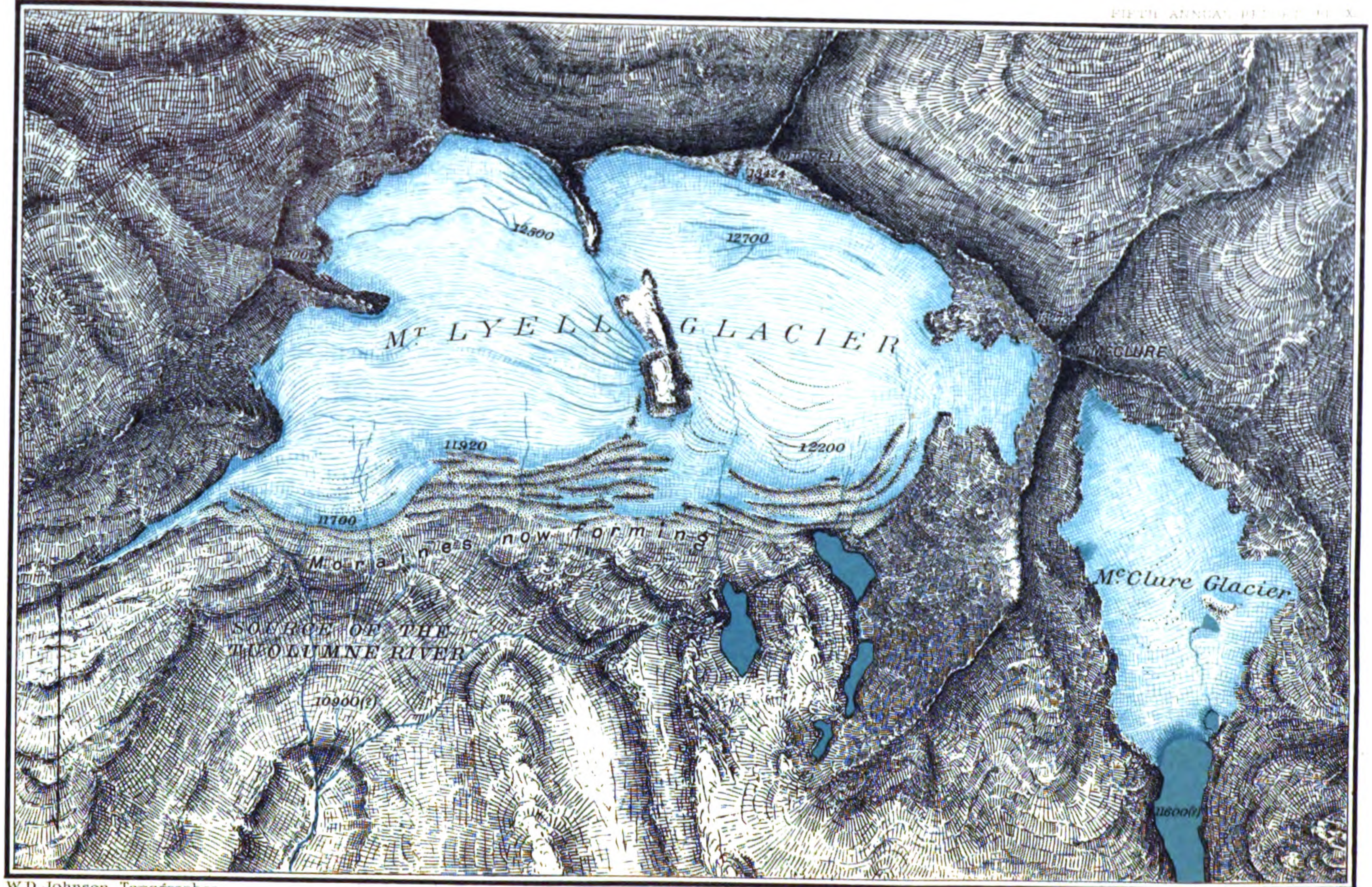
[illegible] American Journal of Science, Vol. [illegible] Third [illegible] 187[illegible], p. [illegible]

[2] Mount [illegible] Lyell Glacier is also referred to by [illegible] Proceedings of the Boston Society of Natural History, Vol. XV, 187[illegible], p. [illegible]



W. D. Johnson, Topographer.

Julius Bien & Co. Lith.

I. C. Russell, Geologist.

MT LYELL GLACIER.

Scale 3½ inches = 1 mile.

to have a motion of a fraction of an inch per day. It is probable that these small ice-bodies are what we have called "ice-tongues" in describing our observations of last summer. In an article entitled "In the heart of the California Alps,"[10] Mr. Muir gives some account of the glaciers about Mount Ritter, combined with enthusiastic descriptions of the magnificent scenery of the Sierra. In another article from the same pen, "Living Glaciers of California," published in Harper's Magazine,[11] a number of illustrations of glacial scenery are introduced, together with popular descriptions of numerous *névés* and ice-fields.

Prof. Joseph Le Conte visited the High Sierra during the summers of 1872 and 1873, and in company with Mr. Muir examined the summit of Mount Lyell.[12] While describing the records of the ancient glacier that once filled the Tuolumne Valley, Professor Le Conte says,[13] that what interested him far more than anything else seen during his journey "was that the main branch of the Tuolumne Glacier, far up among the cliffs and peaks of Mount Lyell, *still exists as a living glacier*, in feeble state of activity it is true, but certainly living." Professor Le Conte accepts Mr. Muir's measurement, and concludes that "*the glacier motion still exists.*"

That the Lyell Glacier was more completely hidden by snow when examined by LeConte in 1872, than ten years later when seen by the writer, appears from the following paragraph, from the American Journal of Science:

"Here, then, on Mount Lyell we have *now existing, not a true glacier*, perhaps, certainly *not a typical glacier* (since there is no true glacier-ice visible, but only snow and *névé*; and certainly *no protrusion of an ice-tongue beyond the snow field*), yet nevertheless *in some sense a glacier*, since there is true differential motion and a well-marked terminal moraine. It is in fact a glacier in feeble old age, a feeble remnant of the Tuolumne Glacier, a glacier once of great proportions and playing an important part in mountain sculpture but now in its second childhood."

Le Conte found the surface of the snow on the *névé* of the Lyell Glacier "traversed in a direction at right angles to the slope by *sharp blades* of half compacted ice about 2 feet apart and 2, 3, 4, or even 5 feet in height; * * * the crests of the blades were not continuous, but irregular both in outline and trend, very much in this respect like ripple marks or like waves."[14] The explanation offered—suggested by Mr. T. C. Gardner—is that the blades are due to the action of the sun or wind ripples forming on the surface of the *néré*.

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[10] Scribner's Monthly, Vol. XX, 1880, p. 345.

[11] Vol. LI, 1875, p. 769.

[12] A portion of the results of these journeys was published in a paper, "On some of the ancient glaciers of the Sierra," Proceedings of the California Academy of Sciences, Vol. IV, 1872, p. 159; and also, in a more extended form, in the American Journal of Science, Third series, Vol. V, 1873, p. 325. See also Le Conte's Elements of Geology, Revised Edition, 1882, p. 602.

[13] Page 332.

[14] American Journal of Science, Third series, Vol. V, 1873, p. 332.

[illegible]

[illegible] showing Mount Lyell [illegible] [illegible] [illegible] Changes of [illegible] [illegible] Sierra Nevada [illegible] rocks [illegible] [illegible] exception [illegible] dis[illegible] [illegible]

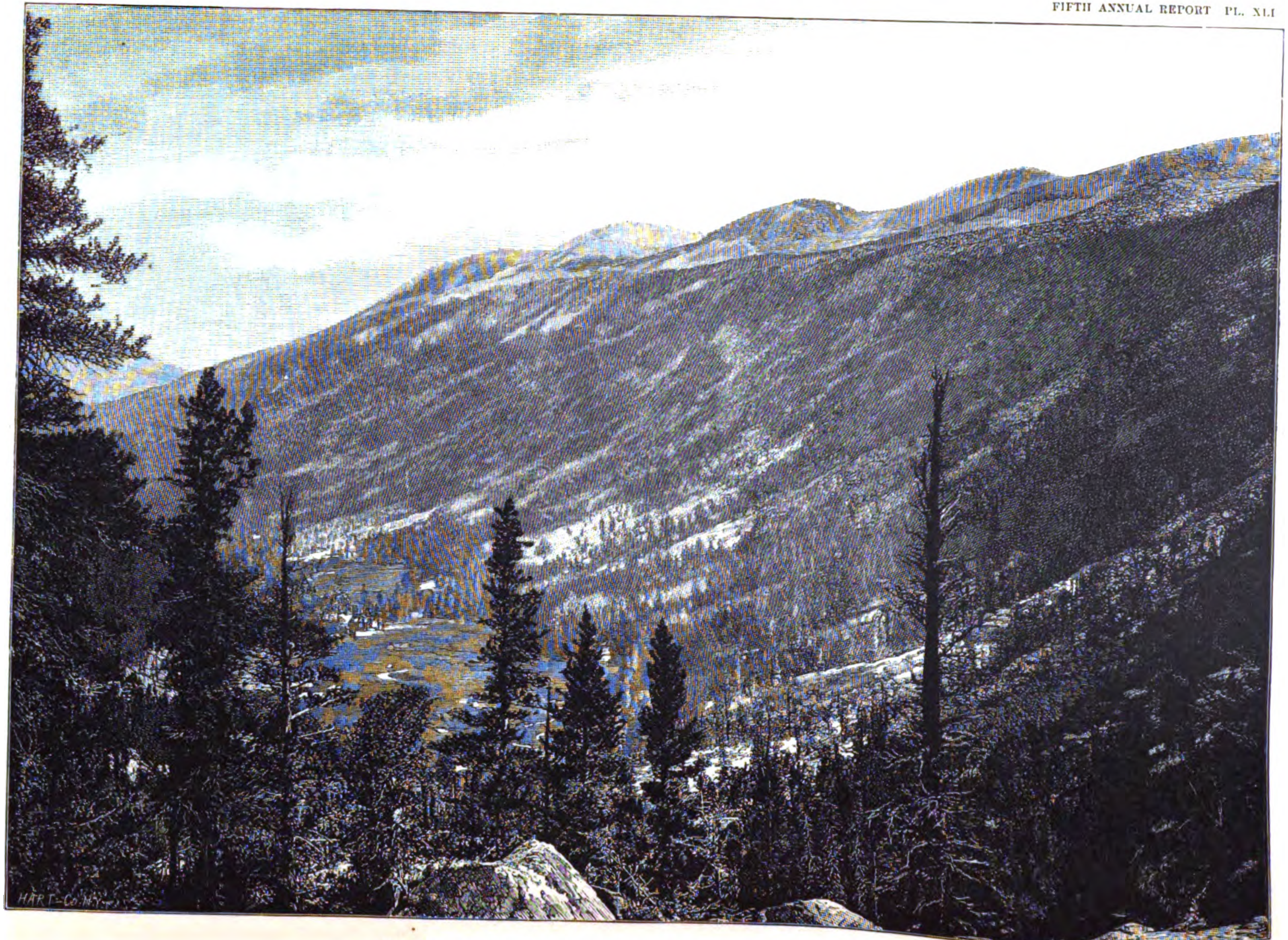
[illegible] by the U. S. Geological Survey [illegible] of [illegible] seems as yet to have been [illegible] glaciers [illegible] Alaska not [illegible] except [illegible] the [illegible] of the Pacific coast. [illegible] in the higher portions of the Sierra Nevada, the Rocky Mountains [illegible] having been sufficiently explored to ascertain [illegible]" It will be noticed that this passage was published in 1884, or ten years later than Muir's and Le Conte's observations [illegible] of Professor Whitney's work the notes of Messrs. King and Gardner, made in 1868 while exploring the eastern slope of Mount Dana, are transcribed as follows: "In a deep *cañon* snow [illegible] north on the east slope (of Mount [illegible]) [illegible] 200 yards wide, and about half a mile long. It has moved down [illegible] for 30 or 40 feet this year, leaving a deep [illegible] between the [illegible] one wall and the ice." In connection with the observations [illegible] Whitney remarks that it is doubtful whether these residual masses of ice can with propriety be called glaciers."

[illegible] Mr. Muir's observations, as is shown by several [illegible] passages in his report of the Exploration of the 40th Parallel,[2] but adds no new information on the subject.

From the quotations that have been given it will be seen that the question of the existence of glaciers in the Sierra Nevada has been decided differently by different observers, who perhaps saw the mountains under diverse conditions as regards their snowy covering. In winter the glaciers are buried so deeply beneath accumulations of snow that no one would suspect their existence; it is only late in summer, when the snows have decreased to a minimum, that they are to be seen to the greatest advantage. That Mr. Muir was correct in classing many of the snow masses as glaciers is sustained by recent investigation, but the observations on which he based his determinations seem not to have been sufficient to convince all observers who visited them when the mountains were more completely snow-clad than at present.

[1] Memoirs of the Museum of Comparative Zoölogy of Harvard College, Vol. VII, [illegible], No. 2, p. 26.

[2] Vol. I, pp. 467, 478.



VIEW DOWN THE TUOLUMNE VALLEY FROM MOUNT LYELL

In the publications of the Geological Survey of California no mention is made of existing glaciers in the Sierra Nevada. The frontispiece of Volume I (Geology), showing Mount Lyell from the head of the Tuolumne, and also a sketch of the summit of the peak, forming Fig. 73, indicate that the mountains were then far more heavily mantled with snow than when visited by the writer in 1882 and 1883. Prof. J. D. Whitney, in his work on "Climatic Changes of Later Geological Time,"[15] says, "It may be stated there are no glaciers at all in the Sierra Nevada proper, and none in the Great Basin or Rocky Mountain ranges, at least south of the parallel of 42°. With the exception of some recent discoveries said to have been made in 1878 in the Wind River Range (about Latitude 43°) by the U. S. Geological Surveying party, of which no definite account seems as yet to have been published, it may be stated that there are no proper glaciers anywhere within the limits of the United States (Alaska not included), except around the great isolated volcanic cones of the Pacific coast. There are certainly none in the higher portions of the Sierra Nevada or the Rocky Mountains, these most elevated regions having been sufficiently explored to ascertain that fact." It will be noticed that this passage was published in 1882, or ten years later than Muir's and Le Conte's observations cited above. On page 30 of Professor Whitney's work the notes of Messrs. King and Gardner, made in 1868 while exploring the eastern slope of Mount Ritter, are transcribed as follows: "In a deep *cul-de-sac* which opens southward on the east slope (of Mount Ritter) lies a bed of ice 200 yards wide, and about half a mile long. It has moved down from the upper end of the gorge for 30 or 40 feet this year, leaving a deep gulf between the vertical stone wall and the ice." In connection with the observations Professor Whitney remarks that "it is doubtful whether these residual masses of ice can with propriety be called glaciers."

Mr. King also rejected Mr. Muir's observations, as is shown by several emphatic passages in his report of the Exploration of the 40th Parallel,[16] but adds no new information on the subject.

From the quotations that have been given it will be seen that the question of the existence of glaciers in the Sierra Nevada has been decided differently by different observers, who perhaps saw the mountains under diverse conditions as regards their snowy covering. In winter the glaciers are buried so deeply beneath accumulations of snow that no one would suspect their existence; it is only late in summer, when the snows have decreased to a minimum, that they are to be seen to the greatest advantage. That Mr. Muir was correct in classing many of the snow masses as glaciers is sustained by recent investigation, but the observations on which he based his determinations seem not to have been sufficient to convince all observers who visited them when the mountains were more completely snow-clad than at present.

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[15] Memoirs of the Museum of Comparative Zoölogy of Harvard College, Vol. VII, 1882, No. 2, p. 25.

[16] Vol. I, pp. 447, 478.

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[1] M[emoirs of the] Museum of Comparative Zoology of Harvard College, Vol. [illegible] [illegible] No. [illegible] p. 2[illegible].

[2] [illegible] pp. 447, 47[illegible].

VIEW DOWN THE TUOLUMNE VALLEY FROM MOUNT LYELL

ANCIENT GLACIERS OF THE SIERRA NEVADA.

In the present essay it was intended to confine attention to living glaciers, but the subject is so intimately connected with the records of the ancient ice-streams which flowed from the same amphitheater that a few words in reference to the former glaciation of the Sierra Nevada, principally in explanation of the topography shown on Plate XXXII, may not be out of place.

Exploration has now been carried far enough to show that nearly all the higher portion of the Sierra Nevada, excepting the very highest peaks and crests, were at no distant date, geologically speaking, loaded with an immense accumulation of snow and ice, forming a vast *névé* from beneath which trunk glaciers flowed down the cañons both eastward and westward from the crest of the range. The ice-streams that went westward were longer and far larger than those which descended the eastern escarpment, for the reason that the western slope is much less precipitous than the eastern, thus affording larger *névés* and necessitating a longer journey before the ice could reach an horizon sufficiently warm to cause it to melt. Precipitation during the Glacial epoch, as at present, was probably most abundant on the western slope of the range, thus assuring abundant supplies for the mighty ice-rivers.

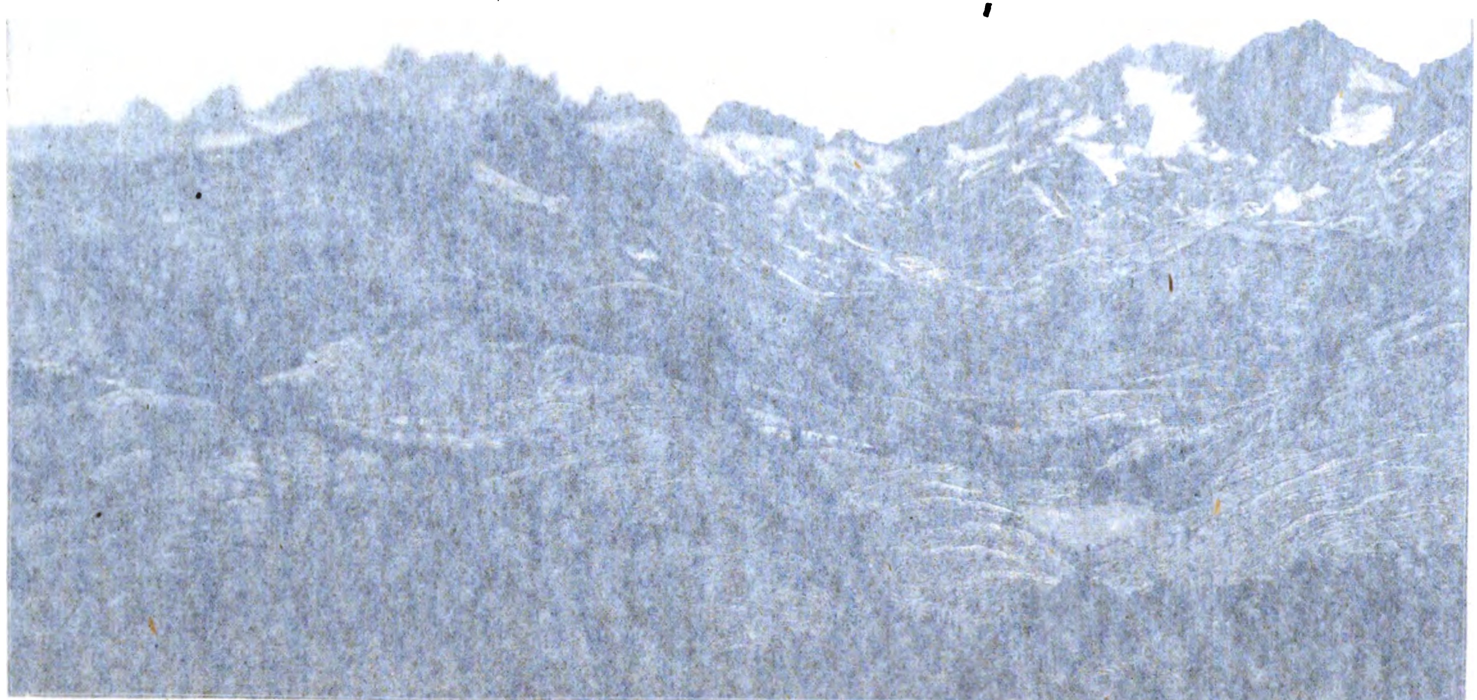
In that portion of the High Sierra to the westward of Mono Lake, which is shown on Plate XXXII, the more pronounced topographical features resulting from the ancient glaciation are conspicuously displayed. The broad-bottomed valley leading northward from Mount Lyell was formerly occupied by the great Tuolumne glacier. This received an important tributary from the region westward of Mount Dana, the path of which is deeply engraved in the topography of the country. The glacier formed by the union of these two ice-streams flowed down the Tuolumne Cañon for 30 or 40 miles, with a depth of between 2,000 and 3,000 feet, and it is believed to have occupied the Hetch-Hetchy Valley, but its full extent is not known. Other magnificent glaciers having their sources about Mount Lyell and Mount Ritter descended the Merced and San Joaquin valleys, which, like the Tuolumne, were considerably modified by ice-erosion. To the eastward of the divide between the drainage to the Pacific and the Great Basin, as indicated on Plate XXXII, the paths of the ancient glaciers are definitely recorded by the smoothed and rounded character of the valleys they occupied. Their channels are frequently fringed with lateral moraines, which in some instances were carried beyond the mouths of the cañons and prolonged upon the plain as parallel embankments. This feature is especi-

ally illustrated by the moraines at the mouths of Bloody, Parker, and Rash Creek cañons. At Bloody Cañon and Parker Creek two separate extensions of the glaciers are recorded by the morainal embankments. The glacier that flowed down Bloody Cañon advanced upon the plain with a slight deflection to the right, and built out a pair of morainal embankments, as indicated on the map; subsequently the ice retreated at least as far as the mouth of the cañon, and then advanced a second time with a deflection to the left, *i. e.*, northward, and formed a pair of parallel embankments larger than the first. Two similar advances of the Parker Creek glacier are also recorded by the very perfect moraines still remaining. The ice-stream which formerly occupied the valley of Rash Creek was by far the largest that entered the Mono Basin, and has many features of interest, which, owing to their diversity and complexity, cannot be fully described at the present time. As shown by the topography and the well-preserved moraines, this glacier was over 1,500 feet thick where it left the cañon; before reaching the plain it was divided by a high rocky spur into two branches, thus producing the peculiar horseshoe-shaped cañon shown on the map. The more southern branch deposited terminal moraines in such a way as to obstruct the outlet of the valley and cause a reversal of the stream when the glacier melted.

The ancient glaciers of the region embraced in the map are shown approximately on the transparent over-plate accompanying it. The general *névé* region is there indicated by light blue and the more important ice-streams by a darker shade. The glaciation of the *névé* region, embracing nearly all the higher portions of the range, merges so gradually into the records made by the well-defined glaciers which flowed from it that it is frequently impossible to determine the upper limits of the trunk glaciers; their lower courses, however, are usually well defined by lateral and terminal moraines.

The contrast between the existing and extinct glaciers of this region is strikingly illustrated by the map and over-plate, which show that the present glaciers occur at the heads of valleys and cañons that were formerly the channels of magnificent ice-rivers. Could the climatic conditions favorable to the growth of glaciers be reinstated, we should see the present insignificant ice-bodies gradually increase until the ancient channels were again flooded and all the higher portions of the High Sierra buried beneath a vast *mer de glace.*

Many features in the glaciation of the High Sierra will receive further attention in connection with the study of the Quaternary history of the Mono Basin, which is now in progress.



THE MINARETS FROM THE EAST.

. . . at the mouths of Bloody, Parker and . . . Cañon and . . . creek two separate . . . by the . . . embankments. . . . Bloody Cañon . . . upon the plain . . . a pair of . . . apparently the ice retreated at . . . the cañon, and then advanced a second . . . i.e., northward, and formed a pair of . . . the first. Two similar advances of . . . also . . . by the very perfect moraines . . . which formerly occupied the valley of . . . that entered the Mono Basin, and . . . which, owing to their diversity and com- . . . at the present time. As shown by . . . moraines, this glacier was over . . . the cañon; before reaching the plain it was . . . into two branches, thus producing the . . . shown on the map. The more . . . in such a way as to obstruct the . . . a reversal of the stream when the glacier

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. . . between the existing and extinct glaciers of this region . . . by the map and overplate, which show that the . . . at the heads of valleys and cañons that were . . . of magnificent ice-rivers. Could the climatic . . . to the growth of glaciers be reinstated, we should . . . ice-bodies gradually increase until the . . . flooded and . . . the higher portions of the . . . vast *mer de glace*.

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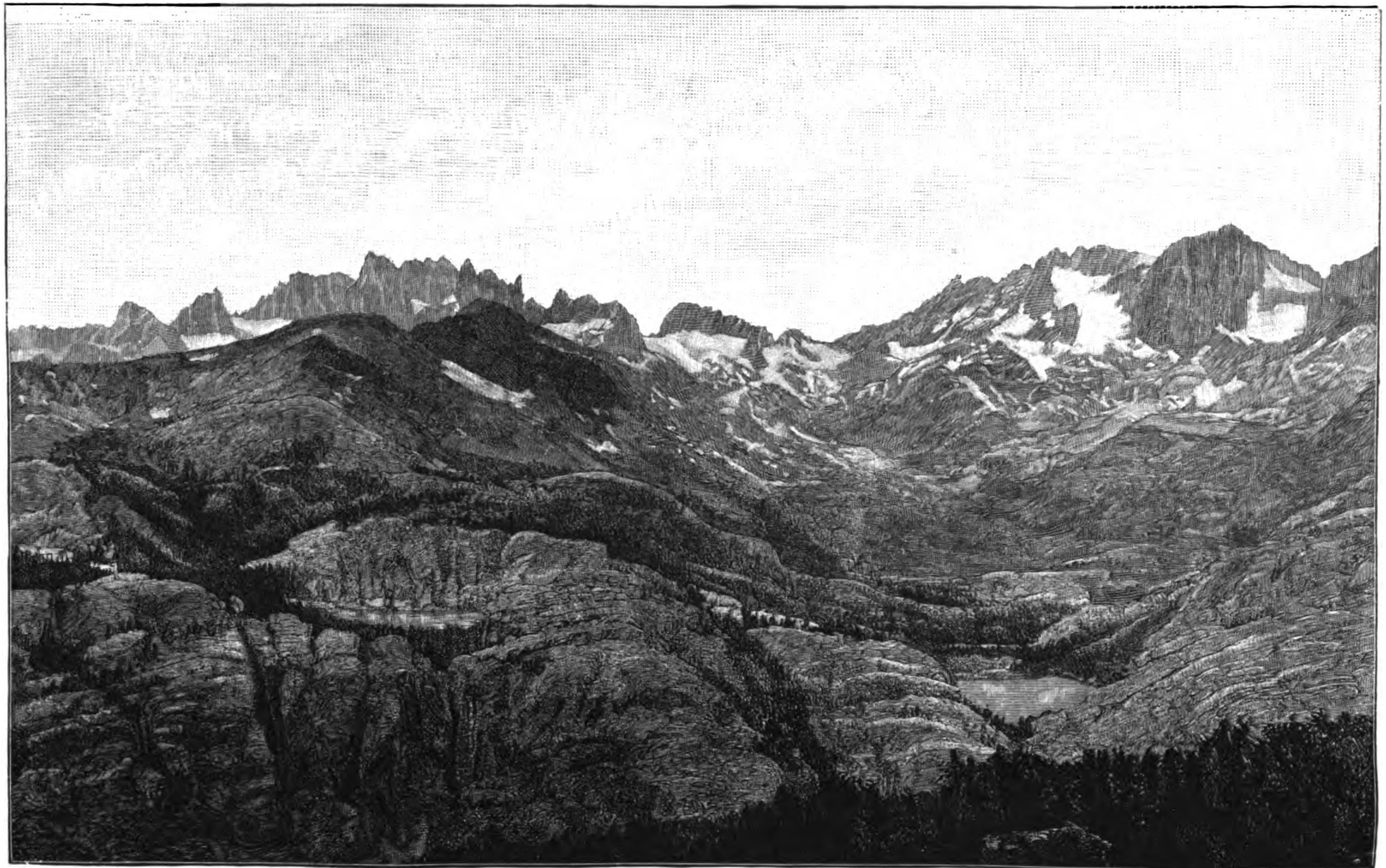

THE MINARETS, FROM THE EAST.

MOUNT SHASTA, CALIFORNIA.

GLACIERS OF NORTHERN CALIFORNIA AND THE CASCADE MOUNTAINS.

The Sierra Nevada is considered as terminating at the northward, near the northern boundary of California; but whether this is in reality the limit of the disturbance that elevated the range remains to be determined. The same great series of mountain forms so pronounced in northern California is continued northward as a prominent topographical feature through Oregon and Washington far into British America. North of California the chain has received the name of the Cascade Mountains, and, unlike the Sierra Nevada, is largely composed of quite recent lava. The volcanic overflows commence southward from what is generally considered as the southern extremity of the Cascade Range and form the grandest peaks in northern California. When the region is more thoroughly known perhaps the southerly peaks will be classed in the same range with Taçoma, Jefferson, Hood, etc. These grand cones, the glory of the Northwest coast, have been but imperfectly explored, yet enough is known to assure us that very many of them are glacier-crowned. Beginning at the south, we propose to present such observations as have been reported concerning the glaciers of the region.

MOUNT SHASTA.

The earliest account of the glaciers of Mount Shasta is given by Clarence King,[17] who ascended the peak in September, 1870, accompanied by several members of the United States Geological Exploration of the 40th Parallel. We transcribe entire the portion of his paper which relates directly to the glaciers:

"On September the 11th we climbed to the top of the lesser Shasta,[18] a conical secondary crater jutting out from the main mass of the mountain on its northwest side. * * * We reached the rim of the cone, and looked down into a deep gorge lying between the secondary crater and the main mass of Shasta, and saw directly beneath us a fine glacier, which started almost at the very crest of the main mountain, flowing towards us, and curving around the circular base of our cone.[19] Its entire length in view was not less than 3 miles, its width opposite our station about 4,000 feet, the surface here and there terribly broken in "cascades," and presenting all the characteristic features of similar glaciers elsewhere. The region of the terminal moraine was more extended than is usual in the Alps. The piles of rubbish superimposed

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[17] American Jour. Sci., Vol. I, Third series, 1871, p. 157. A more popular account was published in "Mountaineering in the Sierra Nevada" by the same author.

[18] Named Shastina on the accompanying map. Plate XLIV.

[19] This is now known as the Whitney glacier; see Plate XLIV.

upon the end of the ice indicated a much greater thickness of the glacier in former days. After finishing our observations upon the side crater, and spending a night upon the sharp edge of its rim, on the following morning we climbed over the divide to the main cone, and up to the extreme summit of Shasta, a point 14,440 feet above the sea level. From the crest I walked out to the northern edge of a prominent spur, and looked down upon the system of three considerable glaciers, the largest about 4½ miles in length and 2 or 3 miles wide. On the next day we descended upon the *south* side of the cone, following the ordinary track by which earlier parties have made the climb. From the moment we left the summit we encountered less and less snow, and at no part of the journey were we able to see a glacier. An east-and-west line divides the mountain into glacier-bearing and non-glacier-bearing halves. The ascent was formerly always made upon the north side, where, as stated, there are no glaciers, and this is why able scientific observers like Professor Whitney and his party should have scaled the mountain without discovering their existence.

"Before and after the ascent of Mount Shasta, a week was given for an examination of the southern half of the volcano. Since the earliest settlement of Strawberry and Shasta Valleys, there has never been such a complete denudation. From June to November, the snow masses were less than they have ever been seen before. This favored very greatly our geological observations, and gave us an excellent opportunity to study the relics of the former great *névé*. We explored one after another all the cañons which, approximately following the radius of the cone, are carved to a greater or less depth into the lava-flows. From the secondary cone around to the eastern side of the main mass are only occasional fields of snow and ice-bodies of a thousand or two feet long, usually quite narrow and lying on the more shaded sides of the ravines. In nature and texture they are quite similar to the true glacier ice, possessing in all cases planes of stratification which indicate the pressure of the formerly overlying masses. There is little doubt that all the scattered snow-fields, that, in the months of August and September, dapple the southern slopes, are the relics of glaciers. They are found in the region of the ancient *névé*, but extending downward into what was formerly the zone of movement.

"Upon reaching the eastern side we found in a deep cañon a considerable glacier, having its origin in a broad *névé* which reaches to the very summit of the peak. The entire angle of this glacier can hardly be less than 28 degrees. It is one series of cascades, the whole front of the ice being crevassed in the most interesting manner. Near the lower end, divided by a boss of lava, it forks into two distinct bodies, one extending in an abrupt rounded face no less than 900 feet in height. Below this the other branch extends down the cañon for a mile and a half, covered throughout almost this entire length with loads of stones which are certainly falling in showers from the cañon walls on either side.

[illegible] of the [illegible]

[illegible] upon the [illegible]

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NORTH.

Gilbert Thompson, Topographer. Julius Bien & Co. Lith.

TOPOGRAPHICAL SKETCH OF MT SHASTA, CALIFORNIA, 1883.

Glaciers

Scale 1/2534. one mile

Névé Fields

Indeed for a full mile the ice is only visible in occasional spots where cavities have been melted into its body, and loads of stones have fallen in. From an archway under the end a considerable stream flows out, milky, like the waters of the Swiss glacier streams, with suspended sand. Following around the eastern base of Shasta, we made our camps near the upper region of vegetation, where the forest and perpetual snow touch each other. A third glacier of somewhat greater extent than the one just described, was found upon the northeast slope of the mountain, and upon the north slope one of much greater dimensions. The exploration of this latter proved of very great interest in more ways than one. Receiving the snows of the entire north slope of the cone, it falls in a great field, covering the slope of the mountain for a breadth of about 3 or 4 miles, reaching down the cañons between 4 and 5 miles, its lower edge dividing into a number of lesser ice-streams which occupy the beds of the cañons. This mass is sufficiently large to partake of the convexity of the cone, and, judging from the depth of the cañons upon the south and southeast slopes of the mountain, the thickness cannot be less than from 1,800 to 2,500 feet. It is crevassed in a series of immense chasms, some of them 2,000 feet long by 30 and even 50 feet wide. In one or two places the whole surface is broken with concentric systems of fissures, and these are invaded by a set of radial breaks which shatter the ice into a confusion of immense blocks. Snow bridges similar to those in the Swiss glaciers are the only means of crossing these chasms, and lend a spice of danger to the whole examination. The region of the terminal moraines is quite unlike that of the Alps, a larger portion of the glacier itself being covered by loads of angular débris. The whole north face of the mountain is one great body of ice, interrupted by a few sharp lava ridges which project above its general level. The veins of blue ice, the planes of stratification, were distinctly observed, but neither *moulins* nor regular dirt-bands are present. Numerous streams, however, flow over the surface of the ice, but they happen to pour into crevasses which are at present quite wide.

"One of the most interesting of all the features of the country was, however, the clearly-defined moraines of the ancient and more widely extended glacier system. Nearly the whole topography of the lower part of the cone is modified by the deposition of glacial material. At an elevation of about 8,000 feet upon the northern or snowless side of the mountain, is a great plateau-like terrace, 2,500 or 3,000 feet wide, extending around one-half of the cone and composed wholly of moraine material. Besides these, long, straight, or slightly-curved medial moraines jut from the mountain in all directions, not unfrequently descending into the valley for several miles."

A brief account of the glaciers of Mount Shasta was contributed by King to an article on gravel ridges in the Merrimack Valley, from the pen of G. F. Wright,[20] in which special attention is given to the mo-

[20] Proceedings of the Boston Soc. of Nat. Hist., Vol. XIX, 1876, p. 60.

raines now forming on the margins of the glaciers, and their resemblance to certain glacial deposits of New England.

In the account of an ascent of Mount Shasta, published in the reports of the Geological Survey of California,[21] no mention is made of the existence of glaciers. In Professor Whitney's recent work, Climatic Changes of Later Geological Time,[22] an account of these glaciers is introduced, but it contains no observations in addition to those already published by King.

In 1882 a topographical survey of the region about Mount Shasta was begun by Mr. Gilbert Thompson, of the U. S. Geological Survey, who has kindly furnished the following notes and sketches, which form an addition to the previous descriptions of the mountain:

"During a portion of the season of 1883 I was engaged in obtaining the topographical details of Mount Shasta, California, and take pleasure in furnishing such information as I can concerning the glaciers now existing on the mountain.

"Mount Shasta is a volcanic peak situated in latitude 41° 24′ 30″, longitude 122° 11′ 34″. The present determination of its altitude above the sea is 14,511 feet.[23] It stands alone and has no connection with neighboring mountains, none of which within a radius of 40 miles attain two-thirds its height. The greatest length of its northwest slope, terminated by little Shasta Valley, which has an altitude of 3,000 feet, is 16 miles. The southwest slope reaches Elk Flat, and descends over 10,000 feet in 8 miles. The highest divide to the northwest is 6 miles distant, and has an altitude of 6,000 feet. The divide of the Sacramento River, 10 miles to the westward, is 3,500 feet above the sea. The ordinates from the summit to the contour of 8,000 feet will vary from 3 to 4 miles in length. The point where the timber growth receives its first check is at an elevation of 8,200 feet; the last tree, however, so diminutive as to hardly cover the palm of one's hand, was found at the altitude of 10,130 feet. Mount Shasta attracts the attention at a distance of over 100 miles, and from nearer points the solemn repose and grandeur of its isolation are impressive.

"The glaciers about the summit of Mount Shasta do not exist under the protection of sheltering cliffs or in the depth of cañons, but occur on the flanks of the mountain and are exposed for three-fourths of the day to the full power of the sun. The streams, having their origin in the melting of the snow, appear suddenly at the foot of the mountain as rushing torrents, loaded with silt; these subside during the latter part of the night and leave pools of clear water, which also gradually disappear. The water again reaches the surface in unexpected places many miles distant as immense springs. The stream channels are thus flooded once a day during the summer, and after the first snow, which occurs about the 1st of October, no more water descends from the snow-fields.

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[21] Vol. I (Geology), pp. 332–351.

[22] Page 27.

[23] Elevation determined with cistern barometer.

KONWAKITON GLACIER, MOUNT SHASTA, CALIFORNIA.

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[1] Vol. I (Geology), pp. 352–351.

[2] Page 27.

[3] Elevation determined with cistern barometer.

KONWAKITON GLACIER, MOUNT SHASTA, CALIFORNIA.

WINTUN GLACIER, MOUNT SHASTA, CALIFORNIA.

... a few snow banks the classification ... lingers in the shadow of protecting cliffs, there are ... especially invite attention. With the exception ... which was named in honor of the former Sec... these have been designated by the following ... Kon...wakiton (mud glacier), Wiatun (Indian tribal name), ... and Bolaw (pretty).

The Konwakiton Glacier is situated on the southeastern slope ... its basin at the head of a deep and rugged cañon. Its ... of about 12,000 feet, and from beneath it a strong stream flows down the gorge at times disappearing ... covered with boulders and débris derived from ... the borders above. On reference to the topographic sketch ... it will be seen that this stream falls in a cascade in the upper portion of the cañon; at a lower altitude it forms another beautiful waterfall about 400 ... in height. The surface of this glacier has an area of about 520,000 square yards. ... nearing the ascent by ... the ... footpath, just as the weary climber turns the "Red ..." at 13,... feet altitude, he is forced to make a short détour on the ... of this glacier, which is ... separated from the wall of rock by a deep crevasse.

"The Wintun Glacier has an area of about 2,0..,000 square ... an average breadth of 1,000 yards, and ... 2,200 yards in length. In its course it flows over two precipices and ... greatly broken, ... ing crevasses inclosing blocks and pinnacles of ... veritable ice-cascades of no mean proportions ... great beauty ... cier forms a true ice-stream ... nates in an ice ... several hundred feet ... the accompanying ... narrowed by ... A close ... morainal mat... The glacier terminates ... from it flows a ... stream which is ... Some distance below the ... a cascade ... feet in height. The walls ... the lower portion of this glacier ... common with ... of ... Shasta, are ... in color and ... however, there are many points of view ... excite the enthusiasm of the traveler.

The Hotlum Glacier is situated northward of ... from it by a series of narrow and precipitous ... formed by a ... of rock which ... to be a medial moraine. The foot ... terminal moraines, at an altitude of 10,500 feet ... rests upon the lower portion of the ice. A ...

"Besides a few snow-banks that last throughout the year, and a few small glaciers in the shadow of protecting cliffs, there are five ice-streams which especially invite attention. With the exception of the Whitney Glacier, which was named in honor of the former State geologist of California, these have been designated by the following Wintun names: Konwakiton (mud glacier), Wintun (Indian tribal name), Hotlum (steep-rock), and Bolam (great).

"The Konwakiton Glacier is situated on the southeastern slope, and fills a basin at the head of a deep and rugged cañon. Its foot is at the altitude of about 12,000 feet, and from beneath it a strong stream flows down the gorge, at times disappearing beneath a flooring of ice covered with bowlders and débris derived from the walls that overshadow it. On reference to the topographic sketch (Plate XLIV) it will be seen that this stream falls in a cascade in the upper portion of the cañon; at a lower altitude it forms another beautiful waterfall about 400 feet in height. The surface of this glacier has an area of about 320,000 square yards. When making the ascent by Sisson's southern foot-trail, just as the weary climber turns the "Red Rocks" at 13,000 feet altitude, he is forced to make a short détour on the *névé* of this glacier, which is usually separated from the wall of rock by a deep crevasse.

"The Wintun Glacier has an area of about 2,000,000 square yards, an average breadth of 1,000 yards, and is 3,400 yards in length. In its course it flows over two precipices and becomes greatly broken by curving crevasses inclosing huge blocks and pinnacles of ice. These are veritable ice-cascades of no mean proportions, affording details of glacial structure of great beauty and interest. Near its terminus the glacier forms a true ice-stream, confined by cañon-walls, and finally terminates in an ice-foot several hundred feet high, which, as indicated in the accompanying sketch, is furrowed by numerous stream-cut channels A close approach to the ice-wall is dangerous because of the stones and morainal material that, at least in summer, are constantly falling as the ice melts. The glacier terminates at an altitude of about 8,000 feet, and from it flows a considerable stream which is always loaded with mud and silt. Some distance below the terminus this yellow stream forms a cascade fully 400 feet in height. The walls of the cañon occupied by the lower portion of this glacier, in common with nearly all the flanks of Mount Shasta, are somber in color and unpicturesque; below the falls, however, there are many points of view that will hold the attention and excite the enthusiasm of the traveler.

"The Hotlum Glacier is situated northward of the Wintun and separated from it by a series of narrow and precipitous spurs. On the north it is bounded by a narrow crest of rock which at first glance might be taken to be a medial moraine. The foot of this glacier ends in an arc of terminal moraines, at an altitude of 10,500 feet, which at certain points rests upon the lower portion of the ice. A thousand streams

formed by the melting glacier find their way over and through the débris field, and render it a treacherous *terrain* to explore.

"Through the *névé* of the Hotlum Glacier two ice-streams may be said to flow, one of which, in crowding past two rocky buttresses, is broken into pinnacles of ice 50 to 60 feet in height, which are of a pearly-blue tint and present a fantastic and beautiful spectacle. The crevasses below the rocks are very deep and wide. Associated with them are wells of water of great depth, having a translucent blue color; these were oval in shape, the longer axis being in the direction of the flow of the glacier. The glacier is 2,500 yards in length, and covers an area of about 3,200,000 square yards.

"The Bolam Glacier, situated on the northern face of the mountain, indicates by the magnitude of its terminal moraine that it carries greater floods of débris than any of its associated ice-streams. At the time of my examination the foot of this glacier had retreated to a considerable distance from the terminal moraines and was divided into two flows. The first crevasse in this glacier occurs at an elevation of about 11,000 feet, and is of great width, length, and depth. From this rent to the terminus of the glacier the ice is broken into rough blocks and is deeply seamed with fissures. The Bolam Glacier is about 3,200 yards in length and approximately 1,800,000 square yards in area. The crest of the terminal moraine skirting its lower limit has an altitude of 10,000 feet.

"To the right of the Bolam Glacier, as represented on Plate XLVIII, a portion of the Whitney Glacier is shown. This is the most typical ice-stream on the mountain, and originates in the *névé* lying on the table at the summit of the peak. In crowding past the east base of Shastina crater, which it has partially undermined, it occasions a constant falling of rocks and débris, and becomes broken into a multitude of blocks, which are reunited as the stream flows on. The Whitney Glacier is 3,800 yards in length and covers an area of 1,900,000 square yards; in October, 1883, its terminus was at an elevation of 9,500 feet above the sea.

"A careful examination of some of the ice-bodies on the western flank of Mount Shasta would perhaps lead to their being classed as glaciers of secondary magnitude; they occur on steep slopes at high altitudes, and all are over 700 feet in length.

"At the time of Mr. King's examination, in 1870, Mr. Watkins, of San Francisco, obtained a number of photographs of Mount Shasta, from a careful examination of which I conclude that there was more snow on the mountain when they were taken than at the time of my visit in 1883; this conclusion is also sustained by the statements of the residents in the vicinity."

MOUNT RAINIER.

In the Proceedings of the California Academy of Sciences for March 6, 1871, it is stated by Professor Davidson that Lieutenant, now General, August V. Kautz, U. S. A., attempted the ascent of Mount Rainier in 1857, but found his way barred by a great glacier. So far as can

[illegible] covers an area of about [illegible] [illegible]

[illegible] Glacier, situated [illegible] the north [illegible] face of the mountain [illegible] associated ice-streams. [illegible] and was divided [illegible] width [illegible] to the [illegible] glacier [illegible] with [illegible]. The [illegible] about [illegible] yards in length and approximately 1,860,000 square yards in area. The [illegible] has an altitude of [illegible]

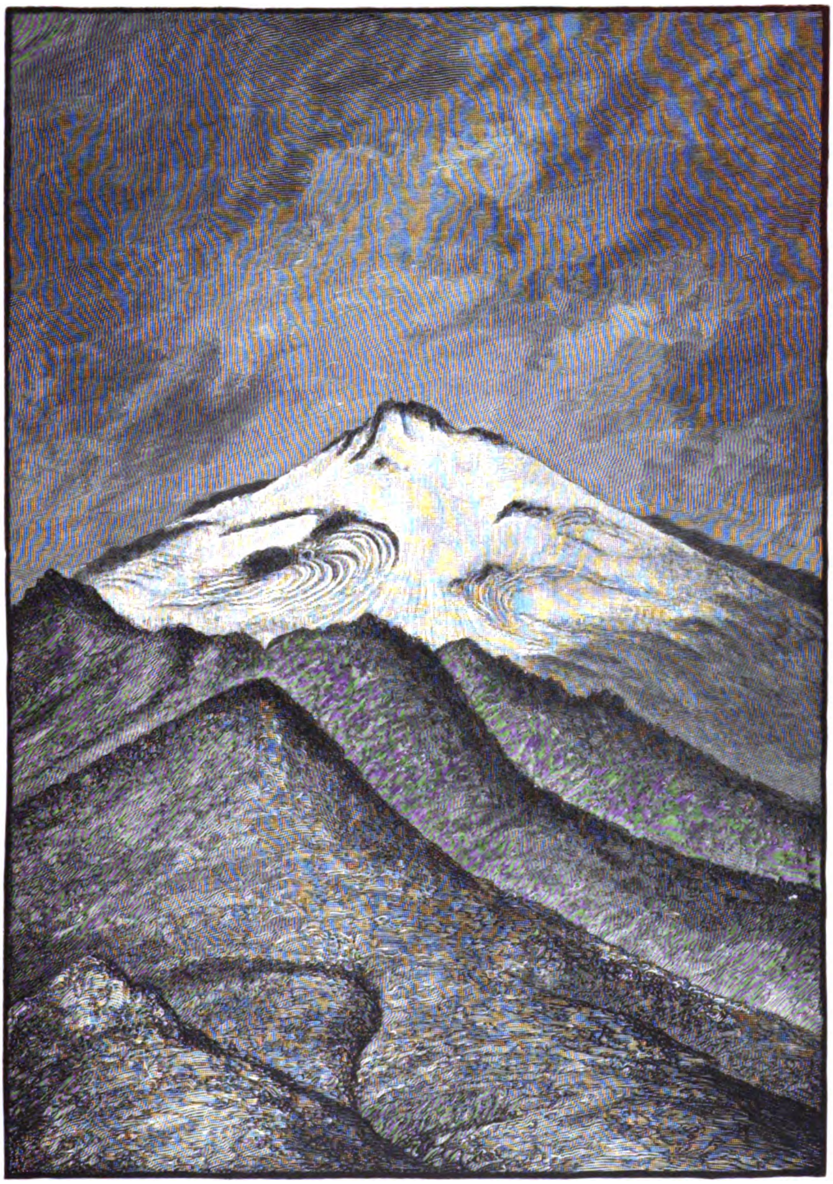
[illegible] right of the [illegible] Whitney Glacier is [illegible] at longitude [illegible] of the peak. In [illegible] of [illegible] a constant [illegible], and becomes broken into [illegible] Whitney Glacier [illegible] covers [illegible] square yards [illegible] of 9,[illegible] feet [illegible].

"A [illegible] examination of [illegible] the western [illegible] of Mount Shasta [illegible] classed as glaciers [illegible] on steep slopes [illegible], and [illegible] are over 700 feet in length."

"At [illegible] of Mr. King's [illegible] 1870 [illegible], San Francisco, obtained a number of photographs of Mount [illegible], a careful examination of which [illegible] that [illegible] was [illegible] the time of my [illegible] 1883 [illegible] by the [illegible] of the [illegible] viewing."

[illegible]

In the Proceedings of the California Academy of Sciences [illegible] 1871, it is stated by Professor [illegible] that Lieutenant [illegible] August V. Kautz, U.S. A., [illegible] the [illegible] of Mount [illegible] but found his [illegible] by a [illegible]



HOTLUM GLACIER, MOUNT SHASTA, CALIFORNIA.

BOLAM GLACIER, MOUNT SHASTA, CALIFORNIA.

Pacific Coast of the United States [illegible] the ascent of Mount [illegible] by Mr. Emmons in Octo[illegible] includes many observations on the [illegible] of the mountain. A [illegible] more detailed and [illegible] was contributed [illegible] to Mr. King's article [illegible] [illegible] read before the [illegible] Society.

The glaciers of Mount [illegible] or R[illegible] [illegible] the principal [illegible] important rivers of W[illegible] [illegible], viz., the Cowlitz, which flows into the C[illegible] [illegible] Puyallup and [illegible] into Puget Sound.

The [illegible] of Tacoma is formed by [illegible]

be ascertained no published account of Kautz's observations has appeared, but from Professor Davidson's statement it seems that he first reported the existence of living glaciers in the United States. An abstract of General Kautz's manuscript account of his excursion is given by S. F. Emmons in an address before the American Geographical Society,[24] but it contains no information of special interest concerning the glacier seen. The address referred to, entitled "The Volcanoes of the

FIG. 140.—Mount Rainier, Washington Territory.

Pacific Coast of the United States," is devoted mainly to a description of the ascent of Mount Rainier by Mr. Emmons in October, 1870, and includes many observations on the glacier examined during his survey of the mountain. As a more detailed and exact account of these glaciers was contributed by Mr. Emmons to Mr. King's article on the glaciers of the Pacific slope,[25] we shall quote from it in preference to the more popular essay read before the Geographical Society:

"The glaciers of Mount Tachoma or Rainier as it is more commonly called, form the principal sources of four important rivers of Washington Territory, viz., the Cowlitz, which flows into the Columbia, and the Nisqually, Puyallup, and White Rivers which empty into Puget Sound.

* * * * * * *

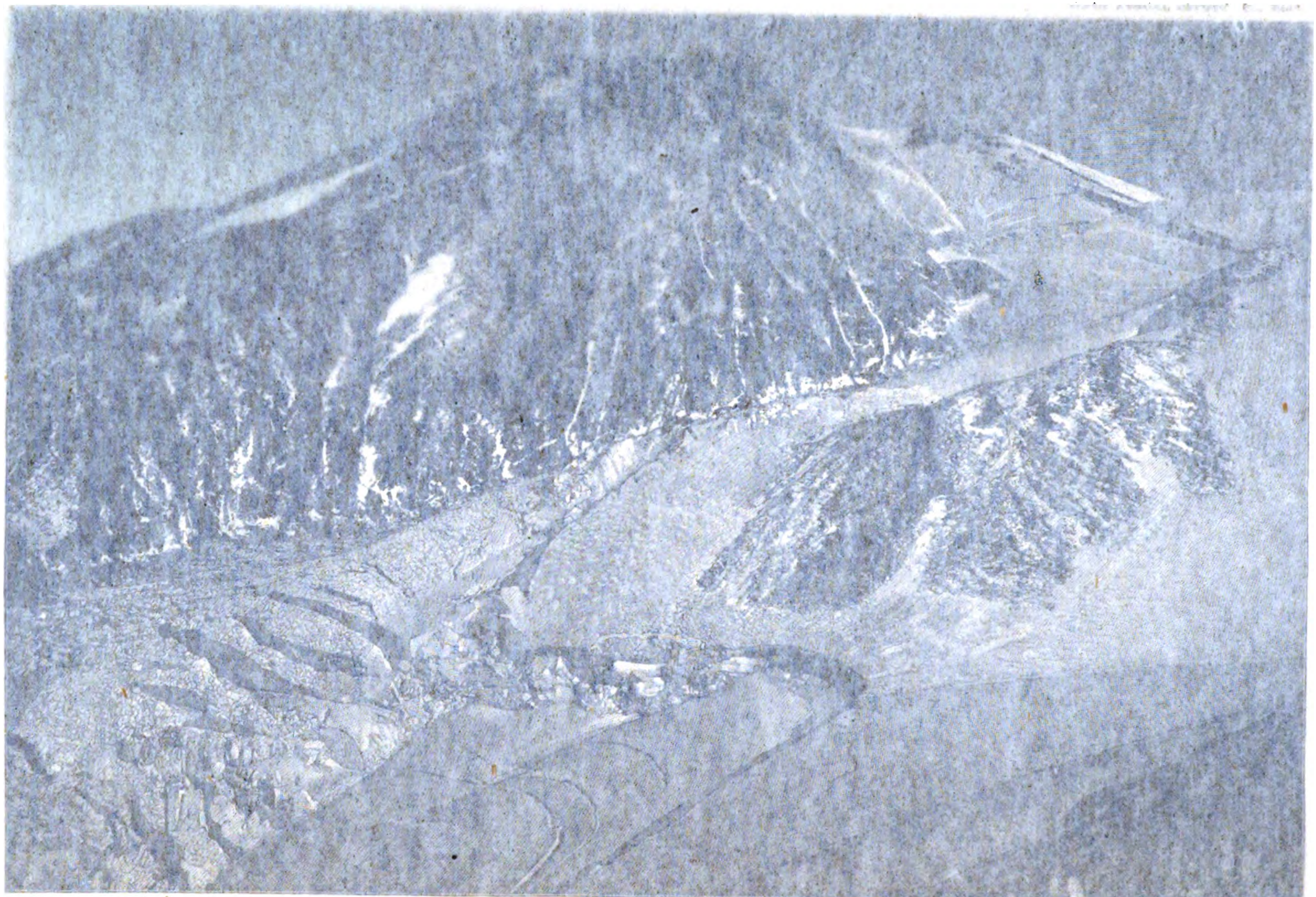
The summit of Tachoma is formed by three peaks, a southern, an

[24] Jour. Amer. Geographical Society, Vol. IX, p. 45.
[25] Amer. Jour. Sci., Third Series, Vol. I, 1871, p. 161.

eastern, and a northwestern; of these the eastern is the highest; those on the south and northwest, being apparently a few hundred feet lower, are distant about a mile and a half to 2 miies from this, and separated by deep valleys. The eastern peak, which would seem to have formed originally the middle of the mountain mass, is a crater about a quarter of a mile in diameter of very perfect circular form. Its sides are bare for about 60 feet from the rim, below which they are covered by a *névé* having a slope of from 28° to 31°. This *névé* extending from the shoulders of the southwestern peak to those of the northern, a width of several miles, descends to a vertical distance of about 2,000 feet below the crater rim, an immense sheet of white granular ice, having the general form of the mountain surface, and broken only by long transverse crevasses, one of those observed being from 1 to 2 miles in length: it is then divided up by the several jutting rock masses or shoulders of the mountain into the Nisqually, Cowlitz, and White River glaciers, falling in distinct ice-cascades for about 3,000 feet at very steep angles, which sometimes approach the perpendicular. From the foot of these cascades flow the glaciers proper, at a more gentle angle, growing narrower and sinking deeper into the mountain as they descend. From the intervening spurs, which slope even more gradually, they receive many tributary glaciers, while some of these secondary glaciers form independent streams, which only join the main river many miles below the end of the glaciers.

"The Nisqually, the narrowest of the three main glaciers above mentioned, has the most sinuous course, varying in direction from southwest to south, while its lower extremity is somewhat west of south of the main peak: it receives most of its tributaries from the spur to the east, and has a comparatively regular slope in its whole length below the cascades. There are some indications of dirt-bands on its surface, when seen from a considerable elevation. Toward its lower end it is very much broken up by transverse and longitudinal crevasses: this is due to the fact, that it has here cut through the more yielding strata or volcanic rock, and come upon an underlying and unconformable mass of syenite. The ice-front at its base is about 500 feet in height, and the walls of lava which bound its sides, rise from 1,000 to 1,500 feet above the surface of the ice, generally in sheer precipices.

"The bed of the Cowlitz Glacier is generally parallel to that of the Nisqually, though its curves are less marked: the ice-cascades in which each originates, fall on either side of a black cliff of bedded lava and breccia scarcely a thousand feet in horizontal thickness, while the mouths of the glaciers, if I may be allowed the expression, are about 3 miles apart. From the jutting edge of this cliff hang enormous icicles from 75 to 100 feet in length. The slope of this glacier is less regular, being broken by subordinate ice-cascades. Like the Nisqually, its lower extremity stretches out as it were into the forest, the slopes on either side, where not too steep, being covered with the mountain fir (*Picea*



HEAD OF WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA

-ern, and a northern; of these the eastern is the highest; those on the south and northwest, being apparently a few hundred feet lower, are distant about a mile and a half to 2 miles from this, and separated by deep valleys. The eastern peak, which would seem to have formed originally the true crater of the mountain mass, is a crater about a quarter of a mile in diameter, of very perfect circular form. Its sides are bare to about 60 feet below the rim, below which they are covered by a névé having a slope of from 28° to 31°. This névé, extending from the summits of the southwestern peak to those of the northern, a width of several miles, descends to a vertical distance of about 2,000 feet below the crater rim, an immense sheet of white granular ice, having the general form of the mountain surface, and broken only by long transverse crevasses, one of those observed being from 1 to 2 miles in length. It is then divided up by the several jutting rock masses or spurs of the mountain into the Nisqually, Cowlitz, and White River glaciers, falling in distinct ice cascades for about 3,000 feet at very steep angles, which sometimes approach the perpendicular. From the foot of these cascades flow the glaciers proper, at a more gentle angle, growing narrower and cutting deeper into the mountain as they descend. From the intervening spurs, which slope even more gradually, they receive many tributary glaciers, while some of these secondary glaciers form independent streams, which only join the main river many miles below the end of the glaciers.

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HEAD OF WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA.

FOOT OF WHITNEY GLACIER, MOUNT SHASTA, CALIFORNIA.

(Looking north.)

[illegible] for several hundred feet [illegible] glacier.

"The general [illegible] heads to the east [illegible] order [illegible] [illegible] passes at [illegible] side, which [illegible] and [illegible] [illegible] [illegible] [illegible] points [illegible] the position of the [illegible] that its [illegible] the [illegible]

"This [illegible] comprehending the White River Glacier, has the [illegible] of a large pinnacle of rock [illegible] part of the crest of the mountain [illegible] peak rising about 2,000 feet above the [illegible] of snow [illegible] upon it. [illegible] Glacier from this spur brings down [illegible] which is traceable to the mouth of the glacier, the [illegible] [illegible] glacier being no medial moraines.

"[illegible] slopes of this spur between [illegible] glaciers [illegible] glaciers [illegible] to the [illegible] height of their initial [illegible] These end generally in perpendicular cliffs over [illegible] theaters at the heads of the smaller streams which flow westward into the Cowlitz. Looking up from the bottom of one of these [illegible] one sees a semicircular wall of nearly 2,000 feet of [illegible] rock, surmounted by about 500 feet of ice, from under which small [illegible] of water issue, falling in silvery cascades on to the green [illegible]

"A [illegible] of high jagged peaks connects this spur with the [illegible] of the Cascade Mountains to the east, and forms the watershed between the White and Cowlitz Rivers. From the connecting saddle one can look northward across the brink of six glaciers, which all contribute to the White River; of these the first four come from the triangular [illegible] [illegible] and are of [illegible] little extent. The [illegible] [illegible] however, interesting from the [illegible] which they [illegible] [illegible] both originate in an irregularly oblong basin [illegible] somewhat of an [illegible] ellipse, turning [illegible] its longer diameter [illegible] lets of the glacier [illegible] to the [illegible]. Seen from a high point [illegible] [illegible] form concentric lines generally parallel to the sides [illegible]

nobilis) for several hundred feet above the level of the ice, while the *Pinus flexilis* grows at least 2,000 feet higher than the mouth of the glacier.

"The general course of this glacier is south, but at its extremity it bends to the eastward, apparently deflected from its course by a cliff of older felsitic rock, more resisting than the lava. The consequence of this deflection is a predominance of longitudinal over transverse crevasses at this point, and an unusually large moraine at its western side, which rises several hundred feet above the surface of the glaciers and partakes of the character of both lateral and terminal moraines: the main medial moraine of the glacier joins this near its lower end. This medial moraine proceeds from the cliff which bounds the ice-cascades source of the glacier on the north, and brings down a dark, porous lava which is only found high up on the mountain near the crater. The position of the medial moraine on the glacier would indicate that at least half its mass came from the spur on the east, which is probably the case.

"This spur, comprehending the whole mass between the Cowlitz and White River Glaciers, has the shape of a triangle whose apex is formed by a huge pinnacle of rock, which as its bedding indicates, once formed part of the crest of the mountain, but now stands isolated, a jagged peak rising about 3,000 feet above the glaciers at its foot, so steep that neither ice or snow rest upon it. One of the tributaries to the Cowlitz Glacier from this spur brings down with it a second medial moraine, which is traceable to the mouth of the glacier, though in general these tributary glaciers bring no medial moraines.

"On the eastern slopes of this spur between the two above-named glaciers, spread secondary glaciers, frequently of great width, but owing to the limited height of their initial points, of inconsiderable length. These end generally in perpendicular cliffs overhanging the rocky amphitheaters at the heads of the smaller streams which flow eastward into the Cowlitz. Looking up from the bottom of one of these amphitheaters one sees a semi-circular wall of nearly 2,000 feet of sheer rock, surmounted by about 500 feet of ice, from under which small streams of water issue, falling in silvery cascades on to the green bottom below.

"A ridge of high jagged peaks connects this spur with the main range of the Cascade Mountains in the east, and forms the watershed between the White and Cowlitz Rivers. From the connecting saddle one can look northward across the brink of six glaciers, which all contribute to the White River; of these the first four come from the triangular spur already mentioned and are of comparatively little extent. The first two are, however, interesting from the vein structure which they exhibit; they both originate in an irregularly oblong basin, having the shape somewhat of an inclined ellipse, turning on its longer diameter, the outlets of the glacier being opposite the foci. Seen from a high point the veins form concentric lines generally parallel to the sides of the basin;

the ends of those towards the center gradually bend round until they join together in form of a figure 8, and finally just above the outlets form two small ellipses. They thus constantly preserve a direction at right angles to that of the pressure exerted downward by the movement of the ice-mass, and upward by the resistance to this movement of the rock mass between the two outlets.

"The main White River Glacier, the grandest of the whole, pours straight down from the rim of the crater in a northeasterly direction, and pushes its extremity farther out into the valley than any of the others. Its greatest width on the steep slope of the mountain must be 4 or 5 miles, narrowing towards its extremity to about a mile and a half; its length can be scarcely less than 10 miles. The great eroding power of glacial ice is strikingly illustrated in this glacier, which seems to have cut down and carried away as shown by the walls on either side, and the isolated peak at the head of the triangular spur, in which the bedding of the successive flows of lava, forming the original mountain crust, is very regular and conformable, may be roughly estimated at somewhat over a mile. Of the thickness of the ice of the glacier I have no data for making estimates, though it may probably be reckoned in thousands of feet.

"It has two principal medial moraines, which, where crossed by us, formed little mountain ridges having peaks nearly 100 feet high. The sources of these moraines are cliffs on the steeper mountain slope, which seem mere black specks in the great white field above: between these are great cascades, and below immense transverse crevasses, which we had no time or means to visit. The surface water flows in rills and brooks, on the lower portion of the glacier, and *moulins* are of frequent occurrence. We visited one double *moulin* where two brooks poured into two circular wells, each about 10 feet in diameter, joined together at the surface but separated below: we could not approach near enough the edge to see the bottom of either, but, as stones thrown in sent back no sound, judged they must be very deep.

"This glacier forks near the foot of the steeper mountain slope, and sends off a branch to the northward, which forms a large stream flowing down to join the main stream 15 or 20 miles below. Looking down on this from a high, over hanging peak, we could see, as it were, under our feet, a little lake of deep blue water, about an eighth of a mile in diameter, standing in the brown gravel-covered ice of the end of the glacier. On the back of the rocky spur, which divides these two glaciers, a secondary glacier has scooped out a basin-shaped bed, and sends down an ice-stream, having all the characteristics of a true glacier, but its ice disappears several miles above the mouths of the large glaciers on either side. Were nothing known of the movements of glaciers, an instance like this would seem to afford sufficient evidence that such movement exists, and that gravity is the main motive power. From our northern and southern points we could trace the beds of several large glaciers to

the west of us, whose upper and lower portions only were visible, the main body of the ice lying hidden by the high intervening spurs.

"Ten large glaciers observed by us, and at least half as many more hidden by the mountain from our view, proceeding thus from an isolated peak, form a most remarkable system, and one worthy of a careful and detailed study."

A graphic account of an ascent of Tachoma (Rainier) was published in the Atlantic Monthly[26] by General Hazard Stevens, who ascended the peak in August, 1870.

Frequent references are made in this essay to the numerous ice-streams that originate on the mountain, but no detailed account of glacial phenomena is presented.

MOUNT HOOD.

In August, 1866, Prof. A. Wood ascended Mount Hood, and later in the year gave a short account of his observations before the California Academy of Sciences.[27] During his ascent he encountered chasms of invisible depth in solid blue ice, in which the rush of subglacial streams could be heard. From the summit of the peak it was observed that a deep cañon descended the southeast flank of the mountain, which was partly filled by a glacier evidently in motion. Both terminal and lateral moraines were seen on the border of the glacier, and a torrent of water issued from its terminus.

Mr. Arnold Hague, in his contribution to King's article on the glaciers of the Pacific coast,[28] already referred to, described the existing glaciers of Mount Hood as follows:

"The crater [of Mount Hood] is nearly one-half a mile wide from east to west. The wall upon the inner side rises above the snow and ice filling the basin some 450 feet, while upon the outer side it falls off abruptly for 2,000 feet. This rim of the crater is very narrow; in many places the crest is not more than 2 feet wide.

"Three distinct glaciers have their origin in this basin, each the source of a stream of considerable size; the glaciers of the White, the Sandy, and the Little Sandy Rivers.

"The White River Glacier heads on the eastern side of the crater, and extends in a southeasterly direction. It is nearly a quarter of a mile wide at the head, and about 2 miles long, extending 500 feet below the line of the timber-growth upon the side of the mountain.

"Near the top of the crater a broad transverse crevasse cuts entirely across the glacier. Freshly fallen snow overhangs its projecting banks, the perpendicular walls of ice, making it exceedingly dangerous to approach. At one point only, the fissure may be crossed by an ice bridge. Further down the slope of the glacier transverse crevasses are of frequent

[26] Vol. XXXVIII, 1876, p. 513.

[27] Proceedings, Vol. III, p. 292.

[28] Amer. Jour. Sci., Third series, Vol. I, 1871, p. 165. *Ante*, p. 329.

occurrence, running nearly parallel with each other; most of them are, however, quite narrow. One broad chasm presented clean, sharply cut vertical sides, for nearly 200 feet in depth, of clear deep blue ice. Marginal crevasses, ice caves and caverns occur. Many of the latter are very beautiful and afford fine opportunities for the study of the laminated and veined structure of glacier ice.

"Very many of the phenomena attendant upon glaciers elsewhere may be observed here. The terminal and lateral moraines are well marked and extensive. Medial moraines, however, do not appear, because the glacier has no tributaries. Glacial grooving, glacial débris, and bowlders are quite characteristic.

"The glacier of Sandy River is separated from that of the White River by a high, bare ridge standing boldly up above the ice and dividing the crater into two parts. The glacier descends to the southwest. It is fed by the snow and ice of a somewhat larger area of country, and is considerably broader than the glacier of White River. In length they are about equal.

"An immense amount of glacial débris must be annually carried down the stream, whose waters are heavily charged with fine, light gray trachytic sand, brought down from above by this moving mass of ice. The character of the rock, a brittle, porous trachytic, is such that under the wearing action of the glacier it would be easily eroded and ground to fine powder. The very extensive accumulations of sand-banks which are constantly forming at the mouth of the stream where it empties into the Columbia River, bear ample evidence of the fact.

"The Little Sandy River, a tributary of the main stream, with which it unites, a few miles below the base of the mountain, has its source in the third glacier, which is formed on the western flank of the peak, separated from the Sandy by a high wall, a somewhat broken, irregular ridge of trachytic which extends along the southwest slope of the mountain.

"The upper portion of the *névé* of the glacier is inclined at quite a high angle, and is considerably fissured by broad deep crevasses. It has cut into the sides of the mountain a deep, narrow gorge with bare precipitous cliffs. The glacier and the valley of the Little Sandy are both quite narrow.

"One of the most marked geological and topographical features of Mount Hood and the vicinity is its very extensive system of extinct glaciers, which everywhere gouged out immense trough-shaped valleys, cutting down deeply into the earlier trachytic lava flow of the old volcano. The entire network of valleys were all connected with two main glaciers; that of Hood River on the north and the Sandy on the south. The ancient White River Glacier was undoubtedly very large; but, as far as my observations have yet extended, had no tributaries."

MOUNT BAKER.

Mr. E. T. Colman, of the Alpine Club, ascended Mount Baker in 1869, and published a popular account of his excursion in Harper's Magazine,[29] in which he speaks of glaciers, snow fields, *névés*, crevasses, etc., in such a manner as to indicate that glaciers of very considerable magnitude are now flowing down the mountain. Further exploration of this peak is needed, however, before a description of its glaciers can be written.

In the summer of 1883 Mr. J. S. Diller, of the United States Geological Survey, made a reconnaissance from Mount Shasta northward to the Columbia River, during which he observed glaciers of considerable magnitude on Mount Jefferson, Diamond Peak, and the Three Sisters. Mount Scott and Mount Tielson were found to be free from glacier ice. The group of peaks known as the Three Sisters is considered by Mr. Diller as probably affording the most interesting field for glacial studies in the United States, with the exception of Alaska. The glaciers amid this group of peaks attracted the attention of Dr. Newberry while connected with the Pacific Railroad survey in 1855, but no report of these observations has been published.

When the lofty summits of the Cascade Mountains are more thoroughly explored it will undoubtedly be found that many more are glacier-crowned than have been reported up to the present time. The observations cited above, however, are sufficient to show that the glaciers of America are not insignificant, and not unworthy of comparison with the classic ice rivers of Europe. That the mountains of the Northwest will win world-wide renown for the beauty and interest of their glaciers, as well as for the magnificence of their scenery, is predicted by all who have scaled their dizzy heights.

[29] Vol. XXXIX, 1869, p. 793.

PERMANENT ICE ON THE MOUNTAINS OF THE GREAT BASIN.

The arid region of interior drainage included between the Sierra Nevada and the Wasatch Mountains, known as the Great Basin, is diversified by many rugged mountain ranges, some of which attain an altitude of from 10,000 to more than 13,000 feet. The climate is arid and the country desert-like throughout, except along the margins of streams and where springs come to the surface. The valleys are usually scantily clothed with sage brush, but not infrequently they are absolute deserts, and the mountains, as a rule are bare of vegetation, especially about their more elevated portions. A region more unfavorable for the formation of glaciers could scarcely be found; yet, as shown by the observations of Mr. William Eimbeck, of the United States Coast Survey, there is a body of ice on Jeff Davis peak,[30] one of the highest mountains in the Great Basin, that approaches the condition of a glacier, and indicates that a moderate lowering of temperature would cause glaciers to form on the higher peaks in the central and northern part of the Great Basin. That a moderate climatic change would produce such a result is also evident from the fact that during the glacial epoch, when the higher mountains of Utah and California were buried beneath vast *névé* fields, some of the intermediate ranges, including Jeff Davis Peak, also bore glaciers.

Jeff Davis Peak has an altitude of 13,100 feet; rising 8,000 feet above the valleys that flank it on the east and west, and forming the crowning point of one of the most rugged of the basin ranges. It is situated in Eastern Nevada, about 15 miles from the Nevada-Utah boundary, or, more accurately, in latitude 38° 59′ and longitude 114° 19′, as deter-

[30] This mountain has a number of synonyms. To the Indians it is known as "Too-bur-rit," and to the whites as "Union," "Jeff Davis," "Lincoln," and "Wheeler's" Peak. Capt. J. H. Simpson passed near it in 1859 and named it Union Peak, in reference to its double form when seen from the north. (See Simpson's "Exploration across the Great Basin of Utah in 1859," pages 51 and 121.) Among the settlers in the southern portions of Utah and Nevada it is generally known as Jeff Davis Peak. It is said that two miners, while exploring the mountain during the time of the late rebellion, one being of Southern and the other of Northern birth, named the two spires forming the summit of the mountain respectively Jeff Davis and Lincoln Peaks; by general consent the former has been adopted as the name of the mountain. In 1869 Lieut. G. M. Wheeler and party ascended the mountain, accompanied by Rev. A. F. White, acting State geologist of Nevada, who named it Wheeler's Peak. See "Report on a Reconnaissance in Southern and Southeastern Nevada," Engineer Dep., U. S. A., 1875, p. 62.

The presence of snow about this peak during the summer season was noticed by Captain Simpson, late in July, 1859. ("Exploration across the Great Basin of Utah in 1859," p. 51.)

SKETCH OF JEFF DAVIS PEAK, NEVADA.

mined by Mr. Eimbeck, to whom we are also indebted for the following notes and sketch:

"The most striking feature of the mountain is the deep, broad chasm, dividing the no doubt once continuous hog-back ridge into two distinct peaks, as shown in the accompanying sketch. Measured along the crest line the width of this chasm is 4,000 feet, and its depth not less than 2,000 feet. It lays open to view the entire geologic structure of the mountain, and deep down in the shadow of its walls lies an ice-body, hidden and effectually protected against the direct influence of the sun. When seen in August, 1883, this ice-mass was about 1,500 feet in length, with an average width of about 200 feet. Its depth could not be determined, but was apparently between 20 and 30 feet. The surface of the ice was without fissures or moraines, yet evidently possessed a definite structure as indicated by different tints and shades of bluish green. The average dip of the ice is about 50°, and its elevation above the sea 11,800 feet. Nothing resembling a moraine could be seen near the foot of the ice, but ancient moraines occur about a mile down the cañon, which record the lower limit of the ice-stream which formerly flowed from the same *cirque* that shelters the present ice-body."

Records of ancient glaciers on Jeff Davis Peak were observed by Mr. Gilbert in 1872, who considers the small lakes on the northern slope of the mountain as being confined by morainal deposits[31]. This mountain is thought to be the highest in the Great Basin, and, with the exception of the East Humboldt Mountains, is the only one known to retain snow or ice about its summit throughout the year.

[31] Explorations and Surveys West of the 100th meridian, Vol. III, p. 88.

EXISTING GLACIERS IN THE ROCKY MOUNTAINS.

It has long been known that very large portions of the Rocky Mountains bear evidence of former glaciation, but until quite recently no one had reported the existence of living glaciers in this region. Sierra Blanca, in Southern Colorado, retains patches of snow and ice throughout the year, and the same is true of a large number of the magnificent mountains in the central part of the samê State; but no true glaciers have yet been discovered south of Central Wyoming.

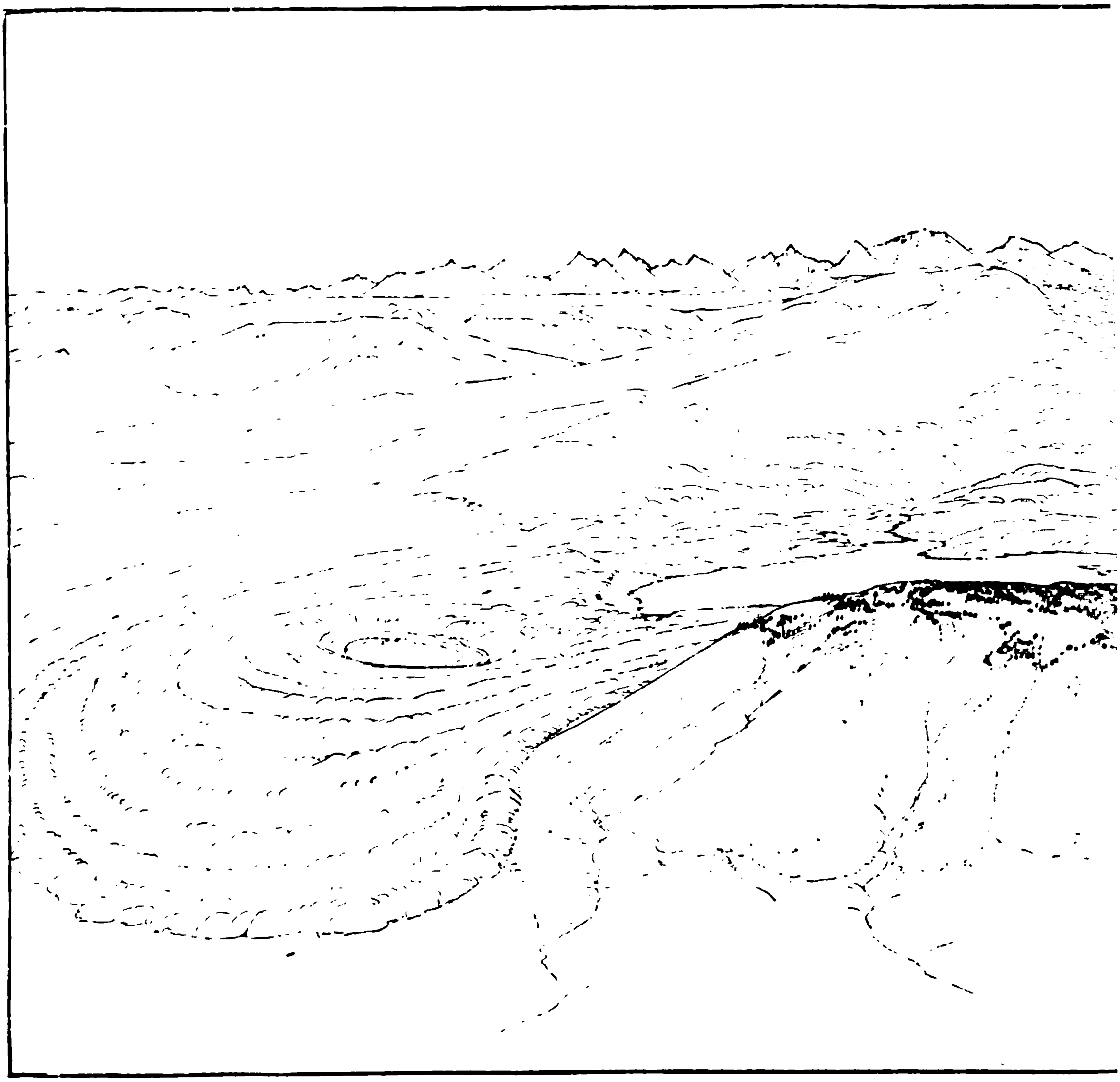
In the preliminary report of the Geological Survey of the Territories for 1878, in charge of F. V. Hayden, brief mention is made of existing glaciers on Wind River and Fremont's peaks, Wyoming, and a sketch of a glacier on Fremont's Peak is given in the atlas accompanying the annual report of the same survey for 1878; but no report of observations relating to these glaciers has yet been published. Mr. W. H. Holmes, one of the geologists of the exploring parties that visited the mountains of Wyoming under the direction of Prof. F. V. Hayden, has kindly contributed the following sketch of his experience among the glaciers still lingering in that region:

"The glaciers of the Rocky Mountains are few and insignificant. Formerly they were numerous and powerful and their deserted beds are found in every highland. The forms of the valleys and the sculpture of the mountains attest their former presence, and long lines of perfectly preserved moraines serve as a record of their magnitude.

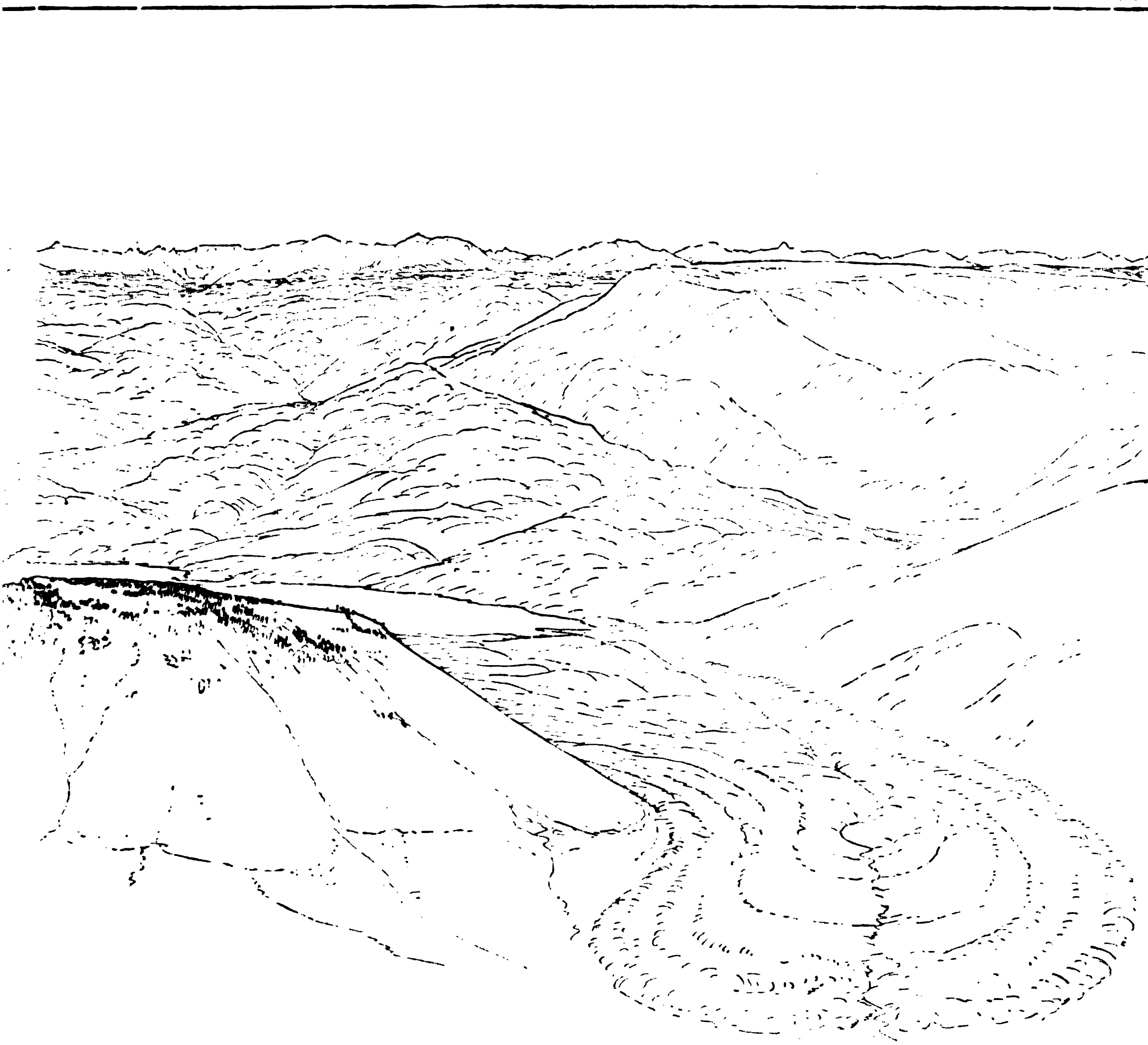
"There is but little evidence of general glaciation. The long even slopes stretching downward from the mountain fronts to the plains owe their conformation to other causes. It is only in the great valleys which descend from the central highlands that we find well-preserved traces of glaciers. In many of these the evidences of recent action are very striking yet we look in vain for great masses of snow or ice.

"In Colorado we followed up the valleys of the Platte, the Arkansas, the Rio Grande, and all the tributaries of the Colorado to the very crests of the ranges, but found nothing, save occasionally under the shadows of the loftiest summits, limited masses of compacted snow which could not be said to have movement and which in no case presented crevasses or ice fronts. The denuded gorges and the polished rocks of the steep upland slopes are only the pathways of avalanches, the offspring of the accumulated snows of a single winter.

"It was not until the summer of 1878 that I came upon what appeared to be a true glacier. This was in the Wind River Mountains of Wyoming. The season had been a dry one, and the snows of the preceding winter had, by the middle of July, almost wholly disappeared leaving



BED OF AN ANCIENT GLAC



.ER, WIND RIVER MOUNTAINS.

exposed to view small fields of perpetual snow, with their well defined crevasses and terminal tongues of ice.

"In company with James Eccles, an Englishman, a geologist, and an Alpine climber, we ascended the most southerly of the great peaks of the Wind River Range. On reaching the crest from the southeast face I came suddenly out upon the brink of the vertical wall which forms the northern face of the peak, and, glancing over, I turned immediately around and shouted, "A glacier." I had looked for six years in vain for this phenomenon, and now experienced a decided feeling of gratification. As some of our party were doubtful as to the existence of glaciers in this region, we were doubly fortunate in having with us a gentleman familiar with the glaciers of the Alps, who, after making a careful examination, had no hesitation in pronouncing this a true glacier. Mr. Eccles published an account of his travels and studies in this region in the Alpine Journal for August, 1879.

"This glacier was of diminutive size, the whole mass of snow and ice being about 2,400 feet wide and less than a mile in length. It lies at the north base of the summit, and is shut in by a high, perpendicular wall which connects with the peak on the west and protects the *névé* field from the rays of the sun during the greater part of the day. The lateral walls are polished to their very crests, and the valley which opens out to the northeast bears the evidence of extensive glaciation as far down toward the plain as the eye could reach.

"From the summit of the peak we had a magnificent view along the serrated crest of the range to the northwest. The summits are generally rugged and sharp; but the high amphitheaters and valleys, although irregular in contour, have their granite faces rounded and polished until they fairly glisten in the sun. Many gem-like lakes are seen, resembling emeralds in their settings of living rock.

"The configuration of this range is well suited to the formation of glaciers. The mass of highland is very wide, and consists of a crest belt above 13,000 feet in height, bordered by a broad plateau from 10,000 to 12,000 feet in height. In past ages the crest has attracted the moisture, and great masses of snow have accumulated upon the broad upper surface of the plateau. This *névé* has given birth to a score of fine glaciers, which have descended by as many depressions in the southwest face of the plateau and deposited a magnificent system of moraines upon the plain below.

"At the end of the glacier-forming period, which may or may not have been synchronous with the glacial epoch, these ice-streams gradually retreated back up the face of the plateau, leaving concentric lines of morainal deposit, within which, at the base of the abrupt slope, we find a number of beautiful lakes.

"The broad polished roadways were finally abandoned entirely and now only limited patches of half solidified snow, the modern representatives of those ancient giants, nestle at the heads of the valleys in the shadows of the loftiest peaks.

[illegible] of the most interesting of these glacier beds is shown in Plate [illegible]. It appeared at the least that the white sheet of ice, on descending [illegible] the plateau and reaching the point, encountered a [illegible] hill which stood directly in its way. The mass of ice, [illegible] the hill, sent out branches to the right and left [illegible] its base and extending a mile or more [illegible] upon [illegible]. The sketch was made from the southeastern end of this hill [illegible] view I have in making the [illegible] selected a point of view sufficiently distant to take in the full [illegible] series of moraines.

[illegible] occupies the depression behind the hill, the drainage of [illegible] the left being into the "New fork" of Green River. No map of [illegible] has yet been made. The moraines are extremely well [illegible] remaining just as perfect as when deserted by the ice. The concentric terminal lines are wonderfully well preserved, especially in the [illegible], where they inclose the small deep lake shown in the view. The lateral moraines which lie up against the face of the [illegible] are not so well defined as in other cases [illegible] down the range where they often exceed 1,000 feet in height. A number of these glaciers have been as much as 20 miles in length.

"In making the ascent of Fremont's Peak we passed up the plateau between the valley just described and that of Fremont's Creek to the north. The part of the plateau lying about the immediate base of the mountain presents the appearance of very recent glaciation, yet there is very little snow to be seen. The opposite side of the crest of the range is much more favorably located for the preservation of snow, and from the summit of Fremont's Peak we discovered a number of small glaciers. These occupy the deep circular amphitheaters immediately under the summits of the Fremont group, and were so far below us that no one ventured down upon them. The snow fields were very large, and about the upper margins showed a number of wide and deep crevasses. Toward the lower ends, which were somewhat obscure from our point of view, were evidences of the movement of the ice, and the extremities were encircled by concentric moraines. I have published a panoramic view of these glaciers in the Twelfth Annual Report of the Hayden Survey. Further exploration in this region will doubtless bring to light other living glaciers.

"The Teton Mountains have formerly given origin to a number of fine glaciers, as demonstrated by extensive morainal deposits on both sides of the range. A number of small glaciers still exist, but in no case have they been closely examined. There are great masses of snow visible about the summits north of the Grand Teton or Mount Hayden, and it is probable that good examples of living glaciers will be found there.

"In passing up the Snake River Valley on the east side of Jackson's Lake I observed that in the deep gorges of the eastern and northern faces of Mount Moran there were at least three small but well devel-

MOUNT MORAN, TETON RANGE, WYOMING.

"One of the most interesting of these glacier beds is shown in Plate LII. It happened in this case that the wide sheet of ice, on descending the steep face of the plateau and reaching the plain, encountered an outlying granite hill which stood directly in its way. The mass of ice, accumulating behind the hill, sent out branches to the right and left, finally encircling its base and extending a mile or more out upon the plain. The sketch was made from the southeastern end of this hill, but in order to give a more comprehensive view I have, in making the illustration, assumed a point of view sufficiently distant to take in the hill and the full series of moraines.

"A fine lake occupies the depression behind the hill, the drainage of which is by the left arm into the "new fork" of Green River. No map of this locality has yet been made. The moraines are extremely well defined, remaining just as perfect as when deserted by the ice. The concentric terminal lines are wonderfully well preserved, especially in the western branch, where they inclose the small deep lake shown in the view. The lateral moraines which lie up against the face of the plateau are not so well defined as in other cases farther up and down the range where they often exceed 1,000 feet in height. A number of these glaciers have been as much as 20 miles in length.

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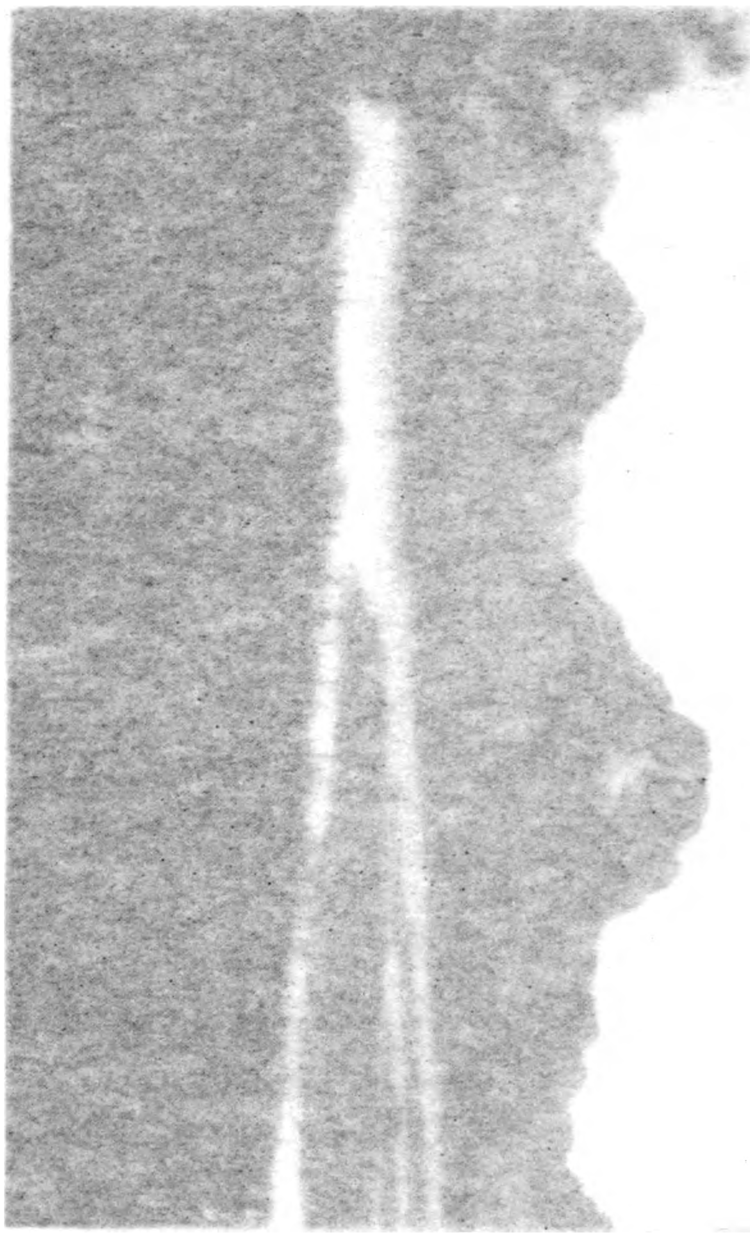


[illegible] of these glacier beds is [illegible] the water sheet of ice [illegible] its way [illegible]

MOUNT MORAN, TETON RANGE, WYOMING.

oped glaciers. The illustration given in Plate (LIII) is from a sketch made through my field-glass, and shows the best example. The area of snow is exceedingly small, but the tongue of ice is well developed, and numerous crevasses expose the fine bluish-green color of the ice. Exposed to the rays of the sun this glacier would disappear in a very few years. The lower extremity of the ice is about 11,000 feet above the sea. The other examples were not so distinctly seen and are not of any great extent.

"The high ranges and plateaus of the Yellowstone country have undergone extensive glaciation, but I was unable to discover anything approaching a glacier in appearance, even in the center of the great mass about the sources of Clark's Fork and the Rosebud."

Existing glaciers were discovered by Professor Pumpelly during the progress of the transcontinental survey, at the head of the Flathead River in northern Montana. No scientific account of these observations has yet been published; but I am informed by Professor Pumpelly that two glaciers were seen in the mountains in which the East Fork of the Flathead rises at an elevation of about 7,000 feet. It was observed that the glaciers broke off suddenly at the summit of precipices 2,000 feet high, and that the waters flowing from beneath the ice had the milky color characteristic of glacial streams. The mountains in which these glaciers were discovered extend northward into British America, and are supposed to reach their greatest elevation north of the boundary. It seems safe to predict that when this little-known region is more fully explored additional glaciers will be found about the peaks known as the Crows and Mountain Head.

GLACIERS OF ALASKA.

In the purchase of Alaska the United States not only acquired a vast territory rich in many natural resources, but also added new wonders to her varied scenery and greatly increased her list of interesting natural phenomena. As the preceding pages show, the glaciers of the United States, previous to the purchase of Alaska, were by no means insignificant, although at that time almost unknown and even now but only imperfectly explored. When we include Alaska our field for glacial study becomes almost unlimited.

The glaciers of Alaska discovered up to the present time are all of the alpine type, except certain masses of buried ice of ancient date, which are probably remnants of accumulations that were formerly of great extent. All the true glaciers are confined to the southern portion of the territory, and evidently depend on topographic conditions for their geographic distribution. The mountains of Alaska occur mostly along its southern border, attaining their greatest elevation in the St. Elias Alps, distant less than 20 miles from the ocean. The entire Pacific border of Alaska is described by all who have explored it as being extremely rugged and mountainous. The same bold topography characterizes the Alaskan Peninsula, and is continued in the Aleutian Islands, which are in reality the peaks of a submerged mountain range. Northward of the imperfectly known Alaskan mountains, which traverse the territory in an easterly and westerly direction, the country is mostly low and not occupied by permanent snow or ice, except in the case of certain buried ice-masses to be mentioned farther on. The glaciers of Alaska occur in valleys and gorges amid the mountains, in the same manner as in similar localities in the Sierra Nevada, Rocky Mountains, etc.; but they are of vast dimensions, owing to the high latitude at which they occur and the abundant precipitation of the region.

In reviewing what has been written concerning the ice-fields of Alaska we find a want of detailed observations of glacial phenomena, but in their stead a number of general sketches and popular descriptions that indicate the richness of the field awaiting exploration. Besides newspaper accounts, always difficult of access, and too frequently wanting in scientific accuracy, there are only a few reports and essays to claim our attention.

The earlier voyagers to the shores of Alaska saw many bodies of ice, some of which we now know were glaciers. Sir Edward Belcher, in his account of the voyage of the "Sulphur," makes brief mention of cliffs of ice on the borders of Icy Bay, near the foot of Mount St. Elias, and states that the shores of the bay were composed of snow-ice to the depth of about 30 feet, which was thought to rest on a low muddy beach. At

Cape Suckling, a hundred miles westward of Icy Bay, similar phenomena were observed.

In the accounts of Vancouver's voyage[32] bodies of ice terminating in cliffs at the water's edge are mentioned as being numerous on the borders of Prince William Sound; and in the same narrative brief descriptions are given of an accumulation of ice in an arm of Stephens Passage, northwest of Sitka, and also among the mountains on the coast opposite Admiralty Island. Two large bays opening north and west from Point Couverdeen are described by Vancouver as terminating in solid mountains of ice rising perpendicularly from the water's edge. Beyond the simple fact of the presence of large masses of ice at the sea-level, the accounts of the earlier voyagers are of little service to the special student of glacial phenomena.

Some of the glaciers along the northern bank of the Stikine River, Alaska, were visited in 1863 by William P. Blake, who published a brief account of his observations in the American Journal of Science.[33] As this is the only account of the magnificent glaciers of the Stikine River region that has been published by a scientific observer, we take the liberty of transcribing it nearly entire:

"The principal stream in the vicinity of Sitka, is the Stickeen (Stikine); which rises in the 'Blue Mountains,' opposite the headwaters of the Mackenzie, and flows in a general southeasterly direction parallel with the coast until it breaks through the mountains east, and a little north, of Sitka. When the snows are melting, the river becomes much swollen, and is then navigable with difficulty by small steamboats for about 125 miles above its mouth. The valley is generally narrow and the river is not bordered by a great breadth of alluvial land.

"In ascending this river one glacier after another comes into view; all of them are upon the right bank of the stream and descend from the inner slope of the mountain range. There are four large glaciers and several small ones visible within a distance of 60 or 70 miles from the mouth.

"The first glacier observed, fills a rocky gorge of rapid descent, about 2 miles from the river, and looks like an enormous cascade. The mountains are greatly eroded by it, for it is overhung by freshly broken cliffs of rock evidently produced by the glacier.

"The second glacier is much larger, and has less inclination. It sweeps grandly out into the valley from an opening between high mountains from a source that is not visible. It ends at the level of the river in an irregular bluff of ice, a mile and a half or two miles in length, and about 150 feet high. Two or more terminal moraines protect it from the direct action of the stream. What at first appeared as a range of or-

[32] Vol. III, p. 185 (1774). Quoted by Blake, Amer. Jour. Sci., Second series, Vol. XLIV, p. 101.

[33] Vol. XLIV, p. 96–101 (1867). Published also, with a map, in a report to the Secretary of State, "Geographical Notes upon Russian America and the Stickeen River. Washington, 1868."

dinary hills along the river, proved on landing to be an ancient terminal moraine, crescent-shaped, and covered with a forest. It extends the full length of the front of the glacier. The following extract from my notes will answer for a description of the end of this glacier.

"We found the bank composed of large angular blocks of granite mingled with smaller fragments and sand. It is an outer and older moraine, separated from a second one by a belt of marsh, and overgrown with alders and grass, and interspersed with ponds of water. Crossing this low space we clambered up the loose granitic débris of the inner moraine, which is quite bare of vegetation and has a recently formed appearance. These hills are from 20 to 40 feet high, and form a continuous line parallel with the outer and ancient moraine. From their tops we had a full view of the ice cliffs of the end of the glacier rising before us like a wall, but separated from the moraine by a second belt of marsh and ponds. Here, however, there were no plants or trees. It was a scene of utter desolation. Great blocks of granite lay piled in confusion among heaps of sand or sand-cones, or were perched upon narrow columns of ice-glacier tables apparently ready to topple over at the slighest touch. The edges of great masses of ice could be seen around pools of water, but most of the surface was hidden by a deposit of mud, gravel and broken rock. It was evident, however, that all this was

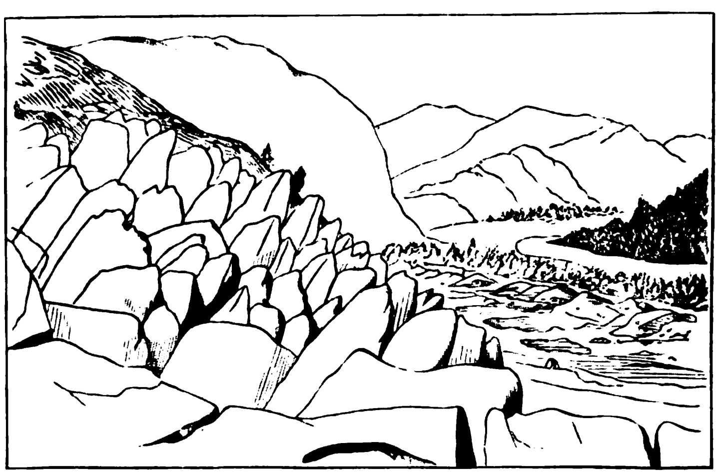


FIG. 141.—End of glacier, looking northwest.

upon a foundation of ice, for here and there it was uplifted, apparently, in great masses leaving chasms filled with mud and water. Over this fearful and dangerous place we crossed to the firmer and comparatively unbroken slope of ice at the foot of the bluff, and afterwards had to climb over snow and ice only, in the attempt to reach the top of the glacier. From below it had appeared to us to be quite possible to ac complish this if we followed the least broken part of the slope, but it

proved to be difficult, and finally impossible. Fissures which could not be seen from a short distance were met at intervals, some of them being so wide that we were forced to turn aside. As we ascended, the crevasses were more numerous but were generally filled with hard snow to which we occasionally trusted. The surface soon became precipitous and broken into irregular stair-like blocks with smooth sides and so large that it was impossible to make our way over them without ladders or tools to cut a foothold. Here we turned and enjoyed the sight of this great expanse of ice, broken into such enormous blocks and ledges. The sun illuminated the crevasses with the most beautiful aquamarine tints, passing into a deep sea-blue where they were narrow and deep. In one direction the ice presented the remarkable appearance of a succession of cones or pyramids with curved sides. In the opposite direction and at the same level the outlines were totally different, showing merely a succession of terraces or steps inclined inward toward the glacier and broken by longitudinal crevasses.

"The annexed sketches were made from this point of view. Fig. 141 is taken looking up the river over the end of the glacier, and shows the pyramids of ice. The line of ponds and the two moraines are seen at the base and the river on the extreme right. Fig. 142 shows the appearance of the glacier in the opposite direction.

FIG. 142.—End of glacier, looking southeast.

"A broad fissure between one level of the ice and the next is filled with snow.

"It is evident that this glacier breaks down in a series of great steps or ledges along the greater part of its front. These steps rise for 20 to 30 feet one above the other, and thus produce a stair-like ascent, while at the same time the numerous parallel fissures at right angles break the surface into rectangular blocks, which on the side exposed to the

sun soon become worn into the pyramids and cones. The difference of outline in opposite directions is thus explained.

"I was inclined to regard the melting action of the water of the river as the cause of this abrupt breaking off of the end of the glacier. There may, however, be a sudden break in the rock foundation at this point, so as to produce an ice-cascade. The following section will perhaps give a clearer idea of the manner in which the glacier breaks down.

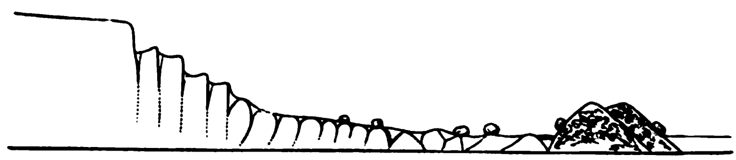


FIG. 143.—Section of end of glacier.

"One or more streams descend under the glacier, and reach the river at different places. The rushing and roaring sound was rather startling at some of the crevasses.

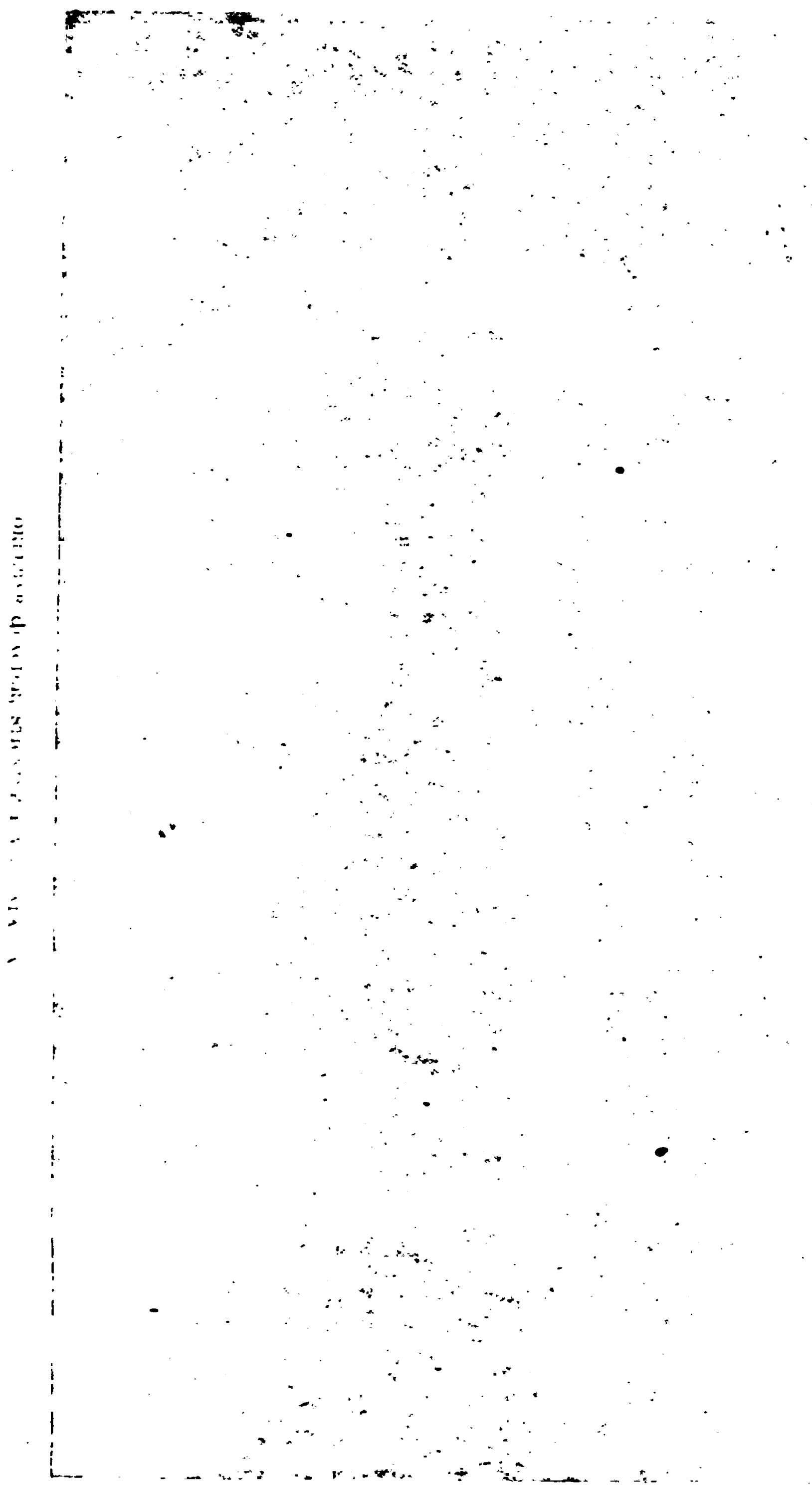
"Judging from the number of loose blocks of rock at the foot of the glacier, the upper surface must be strewn with them, but this could not be verified by observation. Time did not permit a more extended examination. There would be little difficulty in gaining the surface of the glacier from the side, and, perhaps, at some other points along its front. It was impossible to get our Indian guide to accompany us. They have a tradition of the loss of one of their chiefs upon this glacier.

"The ancient terminal moraine of this glacier is significant of an amelioration of the climate. It is also interesting to note the effect which this accumulation of materials from the glacier has had upon the river. It has acted as a dam for the waters, setting them back into the valley for some distance."

An essay from the pen of W. H. Bell, on the Stikine River and its glaciers, appeared in Scribner's monthly for April, 1879, accompanied by a number of illustrations of remarkable scenery. This article, although well worth reading, is diffuse and too popular for scientific accuracy, and its illustrations are sketchy and too greatly exaggerated vertically to be admitted as truthful representations of natural scenery.

The accompanying pictures of the Bernardo and Orlebar[34] glaciers which we have introduced as illustrations of the wonderful glacial scenery of the Stikine River, are direct reproductions from photographs taken by Mr. E. Dossetter, under the direction of Lieut. Col. J. W. Powell, superintendent of Indian affairs of British Columbia. The photographs were kindly placed at the service of the Geological Survey by the director of the American Museum of Natural History.

[34] The location of these glaciers not being given on the photographs, the writer has been unable to correlate them with the descriptions and illustrations published by Blake and others.



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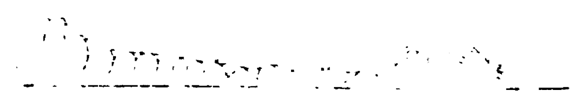

[illegible]

[illegible] The rushing and roaring [illegible]

[illegible] number of loose blocks of rock at the foot of the [illegible] not permit [illegible] the surface of the [illegible] at some other points along its front. [illegible] to get one of the Indian guides to accompany us. They [illegible] of one of their chiefs upon this glacier [illegible] moraine of this glacier is [illegible] It is also interesting [illegible] from the glacier [illegible] for the waters, setting them [illegible]"

An essay [illegible] of W. H. Bell, on the Stikine River and its glaciers [illegible] Monthly for April, 1879, accompanied by a number of [illegible] of remarkable scenery. This article, although well worth [illegible] accuracy [illegible] greatly exaggerated vertically to [illegible] representations of natural scenery.

The [illegible] Bernardo and [illegible] glaciers [illegible] as illustrations of the wonderful glacial scenery of the Stikine River, are direct reproductions [illegible] taken by Mr. [illegible] under the direction of Lieut. Col. [illegible] superintendent of Indian affairs of British Columbia. The [illegible] were [illegible] placed at the service of the Geological Survey by the Director of [illegible] Museum of Natural History.

[illegible] of these glaciers [illegible] on the photographs the writer [illegible] them with [illegible] descriptions and illustrations published [illegible]

ORLEBAR GLACIER, STICKINE RIVER, ALASKA.

Along the shore of the mainland north of the mouth of the Stikine River (approximate latitude 56° 40′) glaciers are reported as occurring on the coast east of Admiralty Island, and will probably be discovered along the Taka River, which, like the Stikine, breaks through a mountainous region near the coast. A number of glaciers, some of which are of great size, occur along the precipitous shores of Glacier Bay and Lynn Canal.[35] Fortunately the positions of these glaciers have been indicated with accuracy on the maps of the U. S. Coast Survey, prepared under the direction of W. H. Dall.

From the head of Lynn Canal a pass leads northwestward to the headwaters of the Yukon, which was followed in 1883 by the military reconnaissance in charge of Lieut. F. Schwatka, who reports four glaciers between Chilcoot Inlet and Lake Lindeman.[36]

Northwestward from Cross Sound, which connects the land-locked waters of Glacier Bay and Lynn Canal with the ocean, the mountains near the coast form a rugged and mostly unexplored chain, giving birth to numerous glaciers. Those flowing toward the ocean have been mapped by Dall, and their positions have been indicated on the charts of the Coast Survey.[37] From the same authority we learn that a number of extensive ice-bodies have been seen on the southern slope of the mountains connecting Mount Vancouver with Mount St. Elias. The northern slopes of these mountains are entirely unexplored. Four more large glaciers have been mapped by Dall on the Kenai Peninsula,[38] projecting from the southern coast in latitude 60° longitude 150°. From this region the general trend of the Alaskan coast is southwestward, the direction being given by the Alaskan Peninsula and the Aleutian Islands. On the peninsula a glacier is reported by Dall as far westward as longitude 162°,[39] and on the Aleutian Islands a small one was discovered by George Davidson[40] on the island of Unalaska at an altitude of about 2,000 feet above the sea, the limit of perpetual snow being 1,000 feet higher. What the extreme westerly limit of the Alaskan glaciers may be remains to be determined.

As will be seen from this brief sketch, nearly all the glaciers reported are near the coast; in fact, the greater part were discovered from the decks of vessels. When exploration is carried inland with the thoroughness and accuracy that characterize Dall's survey of the coast, it cannot fail to extend greatly our knowledge of glacial phenomena. A thorough exploration of the St. Elias Alps is especially important in this connection.

[35] Notes on Glaciers in Alaska, by Thomas Meehan, Proc. Acad. Nat. Sci. Philadelphia, November 6, 1883.

[36] Science, Vol. III, 1884, p. 220.

[37] Chart No. 751.

[38] Chart No. 766.

[39] Coast Survey Chart No. 806.

[40] U. S. Coast Survey Report, 1867, p. 211.

In writing on present glaciation in Alaska,[41] Dall has called attention to the great differences in the character of the ice-masses observed by him during nine years of exploration. To use his own words—

"These might be classed under several heads: as plateau-ice, filling large areas of depression and without motion as a whole, but when sufficiently accumulated, overflowing the edges of its basin in various directions; as valley-ice, filling wide valleys of gentle incline both as to their axes and their lateral slopes, producing masses of ice moving in a definite direction, but without lateral and sometimes even without terminal moraines; as ice-cascades, formed in sharp narrow ravines of very steep inclination, usually without well-defined surface moraines; as typical glaciers, showing névé and lateral and terminal moraines; and lastly, as effete or fossil glaciers, whose sources had become exhausted, whose motion had therefore ceased, and whose lower portions have become smothered by the accumulation of non conducting *débris*. The very existence of one of these last has remained unknown for half a century, though the plateau under which it is buried has been described and mapped by explorers.

"Another form under which ice appears in Alaska is that of solid motionless layers, sometimes of great thickness, interstratified with sand, clay, etc. * * * * * This formation, in which ice plays the part of a stratified rock, extends from Kotzebue Sound [on the west coast of Alaska, at the Arctic circle], where the greatest known thickness of the ice-layer, about 300 feet, has been noted, around the Arctic coast, probably to the eastern boundary. In Kotzebue Sound the ice is surmounted by about 40 feet of clay containing the remains of fossil horses, buffaloes (*Bos latifrons*, etc.), mountain sheep, and other mammals. Farther north the ice is covered with a much thinner coat of mineral matter or soil, usually not exceeding 2 or 3 feet in thickness, and rarely rising more than 12 or 15 feet above high water mark on the sea coast. Its continuity is broken between Kotzebue Sound and Icy Cape by rocky hills composed chiefly of carboniferous limestones, which bear no glaciers and do not seem to have been glaciated. The absence of bowlders and erratics over all this area has been noted by Franklin, Beechy, and all others who have explored it."

A more extended account of the buried ice-masses at Kotzebue Sound was published by Dall in the American Journal of Science,[42] in which the occurrence of the bones of extinct mammals in the clay covering the ice is more fully described. The deposits above the ice in many places had a strong odor of decaying animal matter, which was believed to originate from the remains of the soft parts of the mammoth and other animals whose bones were daily washed out by the sea from the clay talus that fringes the ice-cliffs.

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[41] Bulletin of the Philosophical Society of Washington, Vol. VI, p. 33.

[42] Vol. XXI, third series, 1881, p. 108.

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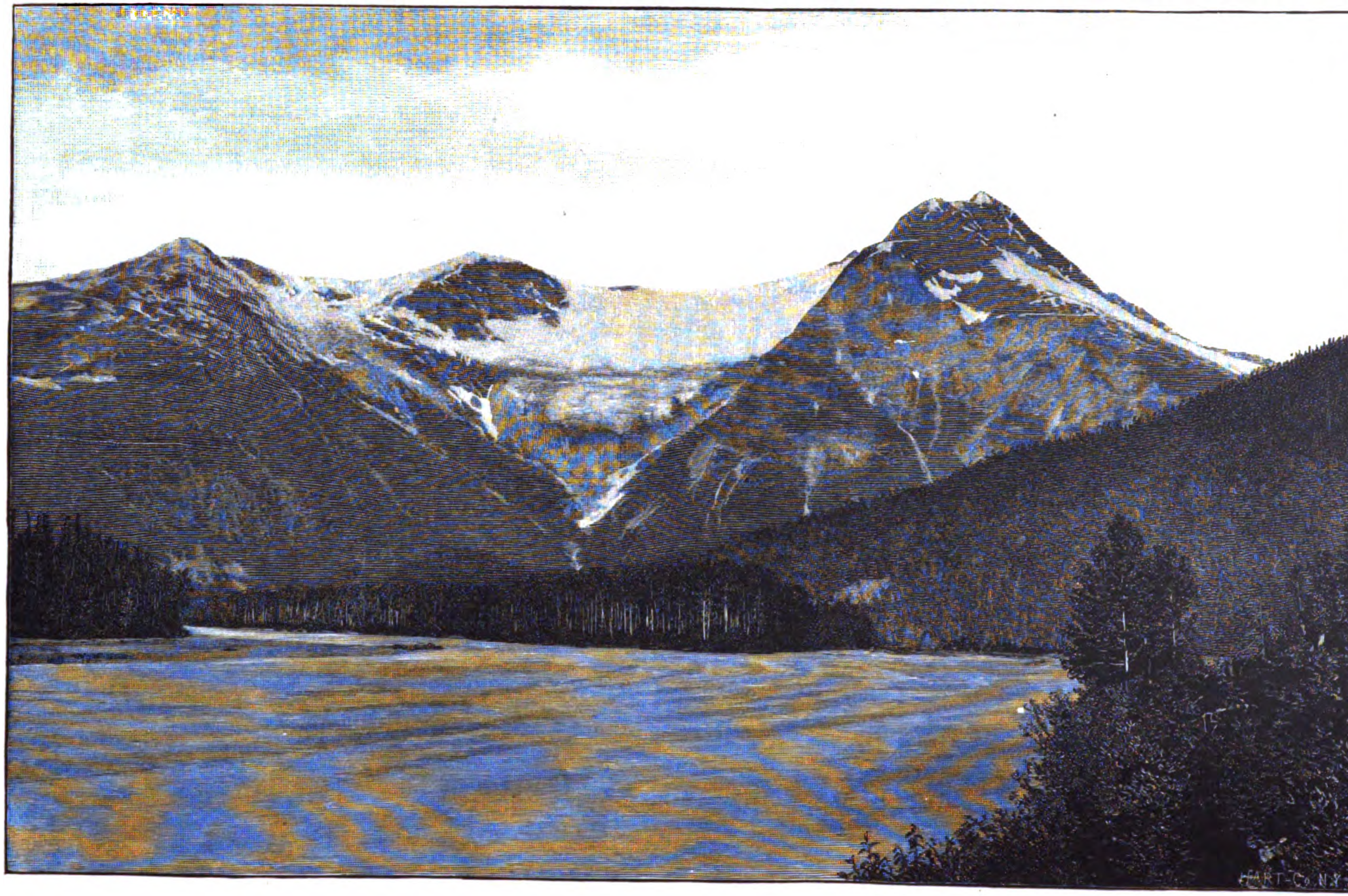
[41] Bulletin of the Philosophical Society of Washington, Vol. VI, p. 3[illegible]

[42] Vol. XXI, third series, 1881, p. 10[illegible].



BERNARD GLACIER, STICKINE RIVER, ALASKA.

rounding country shows no high land or rocky hills from which glaciers might have been derived and then covered with *débris* from the sides. The continuity of the mossy surface shows that the ice must be quite destitute of motion, and the circumstances appear to point to the conclusion that there is here a ridge of solid ice rising several hundred feet above the sea, higher than any of the land about it, older than the mammoth and the fossil horse, and taking upon itself the functions of a regular stratified rock.

A review of the results attained up to the present time in the exploration of the ice-bodies of the United States, shows that we have examples of a great variety of glaciers. Beginning at the south, in the southern portions of the Sierra Nevada, Basin Ranges, and the Rocky Mountains, we find numerous snow-banks and ice-masses that last throughout the summer, but which do not exhibit the characteristics of true glaciers. Farther northward in the Sierra Nevada and Rocky Mountains there is a large number of small glaciers of the Alpine type that have all the peculiar features pertaining to more typical ice-streams. Crowning the hoary giants of the Cascade Mountains are numerous glaciers, flowing through narrow defiles and over precipices by no means unworthy of comparison with the classic ice-fields of Switzerland and Scandinavia. In Alaska the catalogue is still farther extended, embracing numerous examples of Alpine glaciers as magnificent as any in the world. In addition, there are remnants of fossil glaciers that appear to have existed since the glacial epoch—older, certainly, than the now extinct Quaternary mammals which formerly roamed over this continent. Glaciers of the continental type, like those of Greenland, are alone wanting to complete the category.

SKETCH OF PALEOBOTANY.

BY

LESTER F. WARD.

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ILLUSTRATIONS.

SKETCH OF PALEOBOTANY.[1]

By Lester F. Ward.

I.—ON THE TERM "PALEOBOTANY."

The term *paleobotany* has the advantage of brevity over the more common expressions *vegetable paleontology* and *phytopaleontology*, while at the same time its etymologic derivation from two purely Greek words renders it equally legitimate. Still, neither of the other terms should be entirely discarded. While it is always necessary to use the specific term for the science of fossil plants, the practice of employing the generic term *paleontology* when treating of animal remains only seems objectionable. The corresponding term *paleozoölogy* should be recognized, and used whenever the more restricted expressions *vertebrate paleontology* and *invertebrate paleontology* are inapplicable. It is thus only that the terminology of the science becomes consistent and itself scientific.

II.—INTERRELATIONS OF GEOLOGY AND BIOLOGY.

The science of paleontology has two objects, the one geologic, the other biologic. The history of the earth is to a large extent the history of its life, and the record which organic life leaves constitutes the principal index to the age of its successive strata. In paleozoölogy this record is implicitly relied upon and forms the solid foundation of geological science. In paleobotany so much cannot be said, yet it too has already rendered valuable service to geology, and is often the only guide furnished by nature to the solution of important problems.

The contribution that paleontology thus makes to the history of the earth—to geology—is not more interesting than that which it makes to the history of the earth's life—to biology. No questions are more engrossing, nor in fact more practically important for man as one of the living forms developed on the earth, than those that pertain to the origin and development of the various forms of life, and a knowledge of the past life of the globe is that by which we are enabled to understand its

[1] Being a preliminary draft of a portion of the introduction to a "Compendium of Paleobotany," in preparation.

present life as a product of development. Paleozoölogy has already thrown a flood of light upon the true nature of animal life as it now exists, and now paleobotany is rapidly coming to the aid of those who have hitherto so long groped in darkness relative to the origin, development, and distribution of the plant life of the globe.

III.—SCOPE OF THE PRESENT PAPER.

With the second of these objects the present work is only incidentally concerned, its chief aim being to secure, so far as its influence extends, the better realization of the first. Still, it cannot be denied that a considerable degree of mutual dependence subsists between the biologic and the geologic standpoints. To understand the true force of the facts of paleobotany as arguments for geology it is essential that their full biologic significance be grasped. It has therefore been deemed proper, in this introduction to the several tabular and systematic statements which will make up the bulk of the volume and bear chiefly upon the geological aspect of the subject, to consider certain of the more important biologic questions, in addition to the specially geologic ones, and to discuss, from an historical and developmental standpoint, some of the leading problems of modern phytology.

IV.—NEED OF A CONDENSED EXHIBIT.

First of all it must be insisted upon that, notwithstanding the large amount of work that has been done in paleobotany and the somewhat formidable literature which it possesses, the present state of the science is far from satisfactory when regarded as a guide to the attainment of either of the ends above mentioned. Its value, as compared with that of paleozoölogy, in the determination of the age of formations in which vegetable remains are discovered is very small, yet it may well be asked whether the habit of discounting the testimony of fossil plants, acquired at a time when much less was known than now, may not have been continued to an extent which is no longer warranted by the present state of our knowledge. Whether this be so or not, it is at least certain that the real present insufficiency of this department of paleontology as an exact and reliable index to geologic succession is largely due to the exceedingly fragmentary and desultory character of the science, considered as a body of truth, and that a proper and careful collation and systematization of the facts already in the possession of science will add in a high degree to their value in this respect. It was this consideration, so obvious to me from the beginning of my investigations in paleobotany, that moved me to undertake the compilation of this work, and it

has been the growing importance of this same consideration, becoming more apparent at every step, that has impelled and encouraged me throughout its laborious preparation.

It is especially in America that this want of methodical arrangement in paleobotany has been most keenly felt. The most important works on fossil plants have been published since the last attempt of this kind was made in Europe, and very little of our knowledge of the science has ever been embodied in any of the works of this class. The literature of this country is scattered throughout the scientific serials and official publications of the various geological surveys, and the few more comprehensive works that have appeared not only leave this branch of the subject in great doubt and confusion, but contain, besides, many fundamental misconceptions and positive errors.

Whatever degree of inadequacy paleobotany may reveal for the solution of geologic questions, no one can deny that its value can never be fairly judged until its materials are first so classified and arranged that all the light that can be shed by them on any given problem can be directed full upon it and the problem deliberately studied by it. When this can be accomplished, even should it do no more than emphasize the insufficiency of the data, it would, even then, have the effect of pointing out the proper direction of future research with a view to increasing the material and perfecting the data. This work has been conceived and is being conducted primarily to this end of thus focalizing, as it were, the knowledge already extant in this department of research, and of bringing it to bear with its full force, however feeble this may be, upon the questions to whose solution it is capable of being legitimately applied.

V.—FUTURE PROSPECTS OF PALEOBOTANY.

While it is particularly as a contribution to American science, and with special reference to its application to American geology that the work has been undertaken, still, for many and obvious reasons it was found impossible to confine it to purely American facts. The usefulness, for the purpose intended, of any such compilation increases in an accelerated ratio as its scope is expanded, and its value only begins to be really great when it approaches complete universality and compasses the whole field of facts so far as known within its particular department. While this would be true of any science, it is conspicuously so of paleobotany, where, more than anywhere else, the record is so notably incomplete. A more special reason in this case lies in the fact, only recently so strongly felt by paleobotanists, that the floras of the successive epochs in the history of the earth have been differentiating and becoming more and more varied according to their degree of territorial separation, so that in studying them in reverse order we find greater and greater uni-

formity over the whole globe as we go back in time. The fact that even the Tertiary floras of the most remote regions of the world possess a striking resemblance among one another, wholly unknown among existing floras, has only just now fairly revealed itself to science, and found its striking confirmation in the very recent work[3] of Baron von Ettingshausen on the Tertiary Flora of Australia. This uniform character of the fossil floras of different epochs, combined with their variation from one epoch to another, lends hope to paleobotany and leads to the belief that when we shall have learned with precision the true characteristics of each flora—learned to distinguish the accidental from the essential, and geographic from chronologic characteristics—we shall be in a condition to apply the data at hand to the explanation and elucidation of the geologic and biologic history of the earth.

While it is upon the defectiveness of the geologic record, so far as plants help to make it, that the chief stress is usually laid, still, could this record be so edited that it could be made to convey its full meaning it would probably be found that it is really more complete than the biologic record; in other words, the knowledge we have of fossil plants would go further in explaining geologic succession and determining questions of age than it can be made to do in explaining the mode of development, distribution, and differentiation of plant forms on the earth's suface. On the subject of geographical distribution, with which are inevitably bound up many questions of origin, variation, and descent, much has already been written. De Candolle. Hooker, Gray, Grisebach, Ettingshausen, Heer, and Engler have at different times and in numerous ways succeeded in building up a body of valuable literature relating to phytogeography. Since, however, this concerns itself principally with explaining the origin of existing floras, chiefly dicotyledonous, it cannot reach back to the primary and doubtless ever insoluble problems of the differentiation of the great types of vegetation that have successively dominated the plant life of the globe through past geologic ages. Yet, however hopeless the task when the idea of complete solution is considered, it is nevertheless these very questions which are constantly pressing upon the thoughtful student, and he cannot suppress them if he will, or cease to recognize that they are legitimate, and that every, even the least, approach towards their solution is so much clear gain to science.

VI.—INTERDEPENDENCE OF BOTANY AND PALEOBOTANY.

It is only quite recently that botanists have begun to turn their attention to questions of this kind. The overthrow of the doctrine of fixity of species opened the door to such considerations, rendering them legiti-

[3] Beiträge zur Kenntniss der Tertiärflora Australiens. Von C. von Ettingshausen. Denkschr. d. k. k. Akad. d. Wissensch., Bd. XLVII, Wien, 1883.

mate, and the doctrine of the descent of all plant forms from remote ancestors more or less unlike them may now be said to prevail, although few and feeble have been the attempts to indicate the character of the genetic relationships existing among living types. This general subject will be treated later, but it is mentioned here merely to show how it has naturally come about that botanists are now turning their attention towards paleontology as the only source that holds out any promise to them of even partial success in explaining the development of existing floras. The effect of this can but be salutary, and paleobotany is likely to gain as much as botany proper. Even should no success be attained in the direction sought both sciences will gain, since it will bring them into more intimate relations and tend to blend them, as is natural, into one science. Hitherto, it must be confessed, they have been studied too independently. In fact, not only have botanists as a rule ignored the existence of paleontology, but paleobotanists have generally gone on with their botanical classifications and discussions in total disregard of the elaborate systems of the former. Without comparing the results thus independently arrived at, it is safe to pronounce this entire method unwise and improper. To harmonize these results after so long a course of divergence will be a difficult task, and in the effort which is here made in this direction complete success is neither claimed nor hoped for. But if the existing vegetation of the globe has descended from its past vegetation, as almost every botanist as well as paleontologist now assumes, what reason can exist for having two sets of classification? The botanist is thus dependent upon paleontology for all his knowledge of vegetal development and should listen closely to the voice of the past and learn from it the true order in time in which the ancestors of each living type appeared on the earth. Every one must see that this will be of the highest importance as a guide to classification, and will supplement in the most effective manner the data furnished by the developed organs of living plants. We shall ultimately see that, when rightly interpreted, these two sources of proof, instead of conflicting, agree in a most instructive manner, rendering that system of classification which is in harmony with both classes of facts in a high degree probable and satisfactory.

On the other hand, every candid paleobotanist must admit that he can understand fossil plants only as they resemble living ones, and that the botanist, studying the perfect specimen with all its organs of reproduction as well as of nutrition, can alone declare with absolute certainty upon its identity or affinity. This mutual dependence of the two branches of botanical science upon each other is so apparent that it is certainly a matter of surprise that it has received so little recognition by scientific men.

VII.—HISTORICAL REVIEW OF PALEOBOTANICAL DISCOVERY.

A.—BIOGRAPHICAL SKETCHES.

Paleobotany is a science of the nineteenth century. Nevertheless its dawn at the beginning of this century was preceded by a long fading twilight extending entirely through the eighteenth. But even when we consider the nineteenth century alone, its progress shows us that it has as yet scarcely entered into the full light of day. If we judge it by its literature, not always a safe guide, but certainly the best one we possess, we find that the first half of this century produced less than one-fourth as much as the third quarter, and this less than the still unfinished fourth quarter. If we measure the literature, as we may roughly do, by the number of titles of books, memoirs, and papers that have been contributed to it, we will arrive at a rude conception of the accelerated rate at which the science is advancing.

Ignoring for the present certain vague allusions that were made to the subject by the ancients and by writers down to the close of the seventeenth century, some hundred and fifty works might be named belonging to the eighteenth century that bear in a more or less direct way upon vegetable fossils, but this would exhaust the enumeration. A nearly equal number could be named which appeared during the first quarter of the nineteenth century, while fully two hundred titles, including many large works, issued from the press during the second quarter of the century. And yet, as already shown, this was but the beginning, and the true season of interest and activity did not set in until the sixth decade, since which time this activity has steadily, if not uniformly, increased until the present, when the number of works and minor memoirs relating to fossil plants that see the light each year often reaches a hundred.

Although the number of persons who have interested themselves in paleobotany and have published more or less upon it is very great, while those who have become eminent in this field may be counted by scores, still, if we confine ourselves to such only as may be called pre-eminent, who have devoted their lives chiefly and successfully to it, and have either constituted its true founders or enriched in an especial manner its literature and perfected its methods, we may restrict them to eight or ten. If called upon to specify, we might reduce this enumeration to the following great names which stand forth as the true leaders and heroes of this science: Adolphe Théodore Brongniart, Heinrich Robert Göppert, Franz Unger, Leo Lesquereux, Oswald Heer, Abramo Massalongo, Baron Constantin von Ettingshausen, and the Marquis Gaston de Saporta. Whether we consider the number of works actually produced, the volume of this literature, the quality or importance of their

work, or the amount of painstaking labor devoted to the science, we find that much more than half of all we possess of permanent value in paleobotany has emanated from the brains, the hands, and the pens of these eight lifelong and laborious devotees of their chosen science.

It thus appears that the history of paleobotany must consist largely in an account of the labors of a few persons, and had we nothing more to offer than such an account, a fairly just conception of its origin, progress, nature, and scope might be thus afforded. But it might be justly objected that so limited an enumeration not only leaves out of the account some of the most important works and most fertile workers, but also fails to give the true relative importance to those earliest pioneers, who, though they cannot be classed as the true founders of the science, nevertheless first pointed out, and then actually broke, the way to future research and discovery. Let us then extend our list to cover these two important classes, and we still find that though much longer than before it is not so long as to be burdensome. By nearly trebling our former number the selections may be so made that, while not denying great eminence and merit to many others, the history of discovery in vegetable paleontology may be fairly represented by the labors of about twenty-two men. A bare enumeration of these names in the order in which they commenced to write would at least embrace the following:

1.	Johann Jacob Scheuchzer	1709
2.	Ernst Friederich, Baron von Schlotheim	1801
3.	Kaspar Maria, Graf von Sternberg	1804
4.	Adolphe Théodore Brongniart	1822
5.	Henry T. M. Witham	1829
6.	Heinrich Robert Göppert	1834
7.	August Joseph Corda	1838
8.	Hans Bruno Geinitz	1839
9.	Edward William Binney	1839
10.	Franz Unger	1840
11.	Wilhelm Philip Schimper	1840
12.	William Crawford Williamson	1842
13.	Leo Lesquereux	1845
14.	Sir John William Dawson	1845
15.	Oswald Heer	1846
16.	Sir Charles James Fox Bunbury	1846
17.	Abramo Massalongo	1850
18.	Constantin, Freiherr von Ettingshausen	1850
19.	John Strong Newberry	1853
20.	August Schenk	1858
21.	Marquis Gaston de Saporta	1860
22.	William Carruthers	1865

From this list are omitted the names of a considerable number of the younger active workers in this field whose thorough and successful work has already placed them in the front rank, but whose career is so far from completed that its proper characterization will belong to the future historian of the science.

A brief biographical sketch including the mention of some of the more important contributions of each of the above-named paleobotanists may now be made.

1. *Scheuchzer.*—Switzerland, which furnished one of the last and greatest of all the cultivators of this science who have now passed away, furnished also the first name that can with any true propriety be placed in the list of paleobotanists. Although he wrote on many other subjects, and worked in some very different fields, the paleontological works of Scheuchzer are the only ones that possess any enduring value, and although he did not confine his studies to vegetable fossils, he still gave these a much larger share of his attention than they now receive from paleontologists in general, compared to that which is bestowed by them upon the other forms of extinct life. He was born at Zürich in 1672, and died in the same city in 1733. He traveled quite extensively and made large collections of all kinds of curiosities, which he described and figured in numerous works. He regarded all fossils as relics of the Noachian deluge, and gained a permanent place in the history of science by describing the bones of a gigantic salamander as "Homo diluvii testis." His most important work was his "Herbarium diluvianum," first published at Zürich in 1709, but thoroughly revised and republished at Leyden in 1723. In this work many fossil plants are figured with sufficient accuracy for identification. Several of Scheuchzer's other works contain mention of fossil plants, particularly his "Museum diluvianum" (1716), and his "Oryctographia helvetica" (in Part III of the "Helvetiæ historia naturalis," 1716–'18), but their value to the science, as indeed that of all his writings, is now chiefly historical. When, however, we consider that Scheuchzer antedated by almost a full century the earliest properly scientific treatises on paleobotany, we are prepared to overlook his deficiencies, and to regard him as the true precursor of the science.

2. *Schlotheim.*—Ernst Friedrich, Baron von Schlotheim, of Gotha, whose career began with the first years of the present century, is the second name that stands out prominently in the history of paleobotany. Not that there had not been many in the course of the long century which separates him from Scheuchzer who had interested themselves in the study of fossil plants, and who collectively had accumulated the data which rendered the work of Schlotheim possible, but to him is due the credit of first marshaling the evidence from vegetable remains in support of a true science of geology. A sketch of the early struggles and final triumph of strictly scientific principles as drawn from paleontology will presently be presented from the phytological side, and we may therefore content ourselves here with mentioning the grounds upon which Schlotheim's claims rest to a place in the present enumeration.

Born at Almenhausen (Schwarzburg-Sondershausen) in 1764, and educated at Göttingen and Freiburg, he took up the study of mineralogy

and metallurgy, which naturally led him into paleontology, for which he had a strong attachment. In 1801 he published in Hoff's "Magazin" (I, pp. 76–95), at Leipzig, his "Abhandlung über die Kräuter-Abdrücke im Schieferthon und Sandstein der Steinkohlen-Formation," and in 1804 his "Beschreibung merkwürdiger Kraüter-Abdrücke und Pflanzen-Versteinerungen, ein Beitrag zur Flora der Vorwelt" (I. Abtheilung), with fourteen plates, illustrating by accurately drawn figures a large number of Carboniferous plants. In 1805 he was made councilor director and in 1820 president of the College Cameral of Saxe-Gotha, and in 1822 director of the Museum at Gotha. In 1820 he published at Gotha "Die Petrefactenkunde auf ihren jetztigen Standpunkt," the first Heft of which really constitutes the second part (Abtheilung) of the work last mentioned, and the number of plates here reaches twenty-nine, all but the last two of which are devoted to fossil plants. The remainder of this work relates to animal remains, as does also all but Part III of the "Nachtrag" to the work, which appeared two years later.

These works, though few in number, were systematic and conscientious, and constituted by far the most important contribution yet made to the knowledge of the primordial vegetation of the globe. They form the earliest strictly scientific record we have in paleobotany.

3. *Sternberg.*—Kaspar Maria, Graf von Sternberg, though contemporary with Schlotheim, is mentioned after him in this enumeration, first, because his first contribution to paleobotany[3] was made three years later than Schlotheim's first, and, secondly, because his great work on this subject was not completed until after Schlotheim's works were all published and in his hands for use and criticism, and, in fact, not until after Schlotheim's death.

Sternberg was born at Regensburg in 1761 and died at Prague in 1838. He was an assiduous collector, not only of specimens but of books, and when in 1822 he was made president of the Bohemian National Museum he turned over to it all his collections, including 4,000 volumes of rare works. His specialty was botany, on which he wrote many memoirs, but scattered through the different periodicals of the time are to be found some dozen papers relating to fossil plants. The most important of all his works was his "Versuch einer geognostich-botanischen Darstellung der Flora der Vorwelt," which appeared in numbers from 1820 to 1838, and was translated into French by the Comte de Bray.[4] To the eighth number, 1838, was appended Corda's "Skizzen zur vergleichenden Phytotomie vor- und jetztweltlicher Pflanzen." In this work that of all his predecessors, including Schlotheim, is reviewed, and considerable progress made toward the correct interpretation of the record, so far as then known, of vegetable paleontology.

[3] Notice sur les analogues des plantes fossiles. Annales du Muséum d'histoire naturelle, 1804, Vol. V, pp. 462–470, pl. 31, 32.

[4] Essai d'un exposé géognostico-botanique de la flore du monde primitif. Ratisbonne, 1820–1826, fol., 64 pl.

4. *Brongniart.*—Schlotheim and Sternberg may be regarded as pioneers of the science of paleobotany. Brongniart is universally admitted to have been its true founder. The science may properly be said to have been born in 1828, the year in which both the "Prodrome" and the "Histoire des végétaux fossiles" appeared. It was these two works that gave it that powerful impetus which forced its immediate recognition and called into its service a large corps of colaborers with Brongniart, rapidly multiplying its literature and increasing the amount of material for its further study.

Adolphe Théodore Brongniart was born at Paris in 1801 and died in the same city in 1876. His father, Alexandre, was eminent in science, and the author of at least one memoir relating to fossil plants.[5] Adolphe turned his attention early to botany and continued through life to devote himself to living plants; but his great specialty was the study of the extinct forms, and his labors in this field extend through nearly half a century. His very first memoir, "Sur la classification et la distribution des végétaux fossiles en général, et sur ceux des terrains de sédiment supérieur en particulier," which appeared in the "Mémoires du Muséum d'histoire naturelle de Paris" (pp. 203–240, 297–348) in 1822, was one of great merit and importance, as shadowing forth the comprehensive system which he was to elaborate. It was a decided improvement upon the classifications previously proposed by Steinhauer, Sternberg, Martius, etc., and was later employed, with extensive modifications, in the "Prodrome." The great "Histoire," though pushed well into the second volume and enriched by nearly two hundred plates, was unfortunately never finished, and has come down to us in this truncated condition. The causes which led to this result are understood to have been of a pecuniary character, and the author continued his investigations and published his researches for many years chiefly in the "Annales des sciences naturelles de Paris." His next most important work, however, viz., his "Tableau des genres de végétaux fossiles," was published in the "Dictionnaire universel d'histoire naturelle" in 1849. The mere mention of these titles gives a very inadequate idea of the importance of Brongniart's work. The systematic manner in which the science was organized and built up by him made him the highest authority on the subject of fossil plants, and the numerous more or less elaborate memoirs that continued to appear showed that none of the minor details were neglected. Of his reforms in botanical classification we shall have occasion later to speak more particularly.

5. *Witham.*—Henry T. M. Witham, of Edinburgh, was the first of a line of British investigators who looked beyond the external form of fossil plants and undertook the systematic study of their internal structure. It is for this reason rather than on account of the bulk of his works that his name is inserted in this enumeration. He is well known for his de-

[5] Notice sur des végétaux fossiles traversant les couches du terrain houiller. Annales des Mines, Tome VI, 1821, pp. 359–370.

scription of the great Carboniferous tree found in the quarries of Craigleith, and for other similar investigations. One of his principal works is entitled "The Internal Structure of Fossil Vegetables found in the Carboniferous and Oolitic Deposits of Great Britain, described and illustrated," Edinburgh, 1833. The illustrations are numerous and well executed, and form a secure basis for all subsequent researches of the kind.

6. *Göppert.*—Heinrich Robert Göppert, of Breslau, who was born in the year 1800 and who has died since this sketch was first drafted, was the most voluminous writer upon fossil plants that has been produced thus far. In his "Literarische Arbeiten," prepared by himself in 1881, one hundred distinct works, memoirs, and papers are enumerated relating to this subject, and several have appeared since. Nearly an equal number relate to living plants, and a few to medicine, which was his profession. But his work in vegetable paleontology exceeds by far all his other works in its value to science, embracing as it does many large treatises on the Paleozoic flora ("Flora der Uebergangsgebirge"), on the amber flora, on the fossil Coniferæ, on the fossil ferns, etc. Especially important has been his microscopic work upon the structure of various kinds of fossil woods, particularly those of the Coniferæ and the Dicotyledons. Endowed with the true German devotion to his specialty, with keen observing and analytic powers, with a restless activity, exceptional opportunities, and long life, he was able to create for the science a vast wealth of new facts and give it a solid body of laboriously wrought truth. If Brongniart laid the foundations of paleobotany, Göppert may properly be said to have built its superstructure. Though born one year earlier than Brongniart, he did not turn his attention to fossil plants until the latter had been twelve years in that field. His first paper appeared in 1834, or just a half century ago.[6] It was historical in its character. Like many other men who have been destined for a great career, he began it by taking a bird's-eye view of his subject. He did not despise the literature of his predecessors, even though they groped in the darkness of medieval ignorance. With patriotic pride he first told the story of his own countrymen's attempts to elucidate the flora of the ancient world, although even in this paper, he by no means confined himself to the limits of Silesia, and two years later he published a great expansion of this historical research as an introduction to his first great work.[7]

No attempt within our present limits of space to convey an idea of the true merits of Göppert's services to paleobotany could hope to do them justice, and we can only point to the monument he has himself

[6] Ueber die Bestrebungen der Schlesier die Flora der Vorwelt zu erläutern. Schlesische Provincialblätter, August und September 1834. Also in Karsten und Dechen's Archiv, Band VIII, 1835, pp. 232–249.

[7] Systema filicum fossilium: Die fossilen Farnkräuter. Nov. Act. Acad. Cæs. Leop. Car., Tom. XVII, suppl., pp. 1–76.

reared, and enroll his name alongside those of Brongniart, Unger, and Heer.

7. *Corda.*—The propriety of placing Corda's name in this roll of honor may be questioned by some, but his contributions to paleobotany were important, and there can be no doubt that had his life not been prematurely cut off they would have been far more so. Born in 1810 at Reichenberg, Bohemia, he early turned his attention to botany, and especially to close histological investigations in fungology. Humboldt, attracted by his productions, called him to Berlin in 1829, and Sternberg recalled him to Prague in 1834. His "Skizzen zur vergleichenden Phytotomie," appended to Heft 8 of Sternberg's "Flora der Vorwelt," was a valuable addition to that work, and led the way to his two other principal works, "Beiträge zur Flora der Vorwelt," Prague, 1845, and "Die fossilen Pflanzen der böhmischen Kreideformation" (in Reuss's "Versteinerungen der böhmischen Kreideformation"), Stuttgart, 1846. In these works and other of his memoirs a large number of species of fossil plants are named, described, and carefully figured, forming a permanent tribute to the growing science. In 1847 Prince Colloredo sent Corda to Texas to collect scientific material. He remained there two years, making large accumulations, and started back with them in the Bremen steamer Victoria, which was lost in the middle of the Atlantic, and Corda, with all his scientific treasures, went down with her.

8. *Geinitz.*—Only a comparatively small number of Geinitz's papers relate to paleobotany, and a still smaller number are devoted exclusively to that subject; and yet not less than thirty-five titles belong to this department of paleontology. Born at Altenburg in 1814, he has stood for a full half century in the front rank of continental geologists, and still continues his indefatigable labors. His protracted studies into the age and character of the Quadersandstein formation of Germany, in which so many fossil plants have been found, have shed much light upon this difficult horizon, while his investigations in the Permian (Dyas, Zechstein), the Carboniferous, and the Graywacke have always led him to study and describe the floras of these periods. We thus possess in his works a geological authenticity for very many fossil plants, which all paleobotanists know how to appreciate. His "Characteristik der Schichten und Petrefakten des sächs.-böhmischen Kreidegebirges," Dresden, 1839–42, appears to have been his first work relating to our subject, and his paleobotanical labors therefore date from 1839.

9. *Binney.*—If Witham deserved enumeration in our present list for founding the British school of what may be called phytopaleontological histologists, Binney must be admitted in recognition of the extent and importance of his researches in this department. He seems to have commenced publishing the results of his investigations in 1839,[8] and

[8] The first of his papers whose title appears in the "Royal Society Catalogue" is "On a Microscopic Vegetable Skeleton found in Peat near Gainsborough." British Association Report, 1839 (Part II), pp. 71, 72.

continued them without interruption to the end of his life. His most important work, on the "Structure of Fossil Plants from the Carboniferous Strata," published by the Palæontographical Society of London, was commenced in 1868. His death took place in the year 1882.

10. *Unger.*—Franz Unger of Steiermark, who was born in 1800 and died in 1870, was one of the most illustrious of European botanists and paleontologists. His memoirs and books on paleobotany are only less numerous than those of Göppert, and among them is an unusually large number of monographs of great value. His investigations were chiefly confined to the more recent formations, and his "Chloris protogæa," "Flora von Sotzka," "Iconographia plantarum fossilium," and "Sylloge plantarum fossilium" are worthy of special mention. His "Synopsis plantarum fossilium" and "Genera et species" are systematic attempts to compile the known data of the science in condensed and convenient form. His first paper[9] on the subject was published in 1840.

11. *Schimper.*—Although Schimper contributed a paper[10] on fossil plants as early as 1840, and was associated with Mougeot in preparing their important "Monographie des plantes fossiles du grès bigarré de la chaine des Vosges" in 1844, as also with Köchlin-Schlumberger in his "Terrain de transition des Vosges" in 1862, still, but for his great "Traité de paléontologie végétale," the third volume of which appeared in 1874, it is evident that this eminent bryologist would not have been entitled to be also ranked among the great paleobotanists. The "Traité" is unquestionably the most important contribution yet made to the science. Although necessarily to a large degree a compilation of the work of others, still it is by no means wanting in originality, and contains a great amount of new matter. Its chief merit, however, is in its conception and plan as a complete manual of systematic paleobotany. The classification is highly scientific and rational, and the discussion of abstruse points in defense of it is acute and cogent. Every species of fossil plant known to the author is described in Latin, and much independence is manifested in the rejection of synonyms. Very important is the geological classification at the end of Volume III, showing that the author had clear ideas of the uses of the science. The selections for the atlas are always the very best, and not a few of the figures are original. Although not in possession of all the extant data, particularly from America,[11] Schimper succeeded in supplying in this work the greatest need of paleobotany. His great talent as an organ-

[9] Ueber ein Lager vorweltlicher Pflanzen auf der Stangalpe. Steyermärkische Zeitschrift, Grätz, 1840. I have only been able to consult this memoir in Leonhard & Bronn's Neue Jahrbücher (1842, pp. 607, 608), which may not contain it *in extenso*.

[10] Baumfarne, Schachtelhalme, Cycadeen, Aethophyllum, Albertia * * * im bunten Sandstein der Vogesen; Hysterium auf einem Pappel-Blatte der Wetterauer Braunkohle. Leonhard und Bronn's Neue Jahrbücher, 1840, pp. 336–338. Communication dated 14. März 1840.

[11] See "The American Journal of Science," 3d series, Vol. XXVII (April. 1884), p. 296.

izer and text-book writer was again seen in his able contribution to Zittel's "Handbuch der Paläontologie."

Wilhelm Philip Schimper was born at Dosenheim (Alsace) in 1808, and died at Strasbourg, where most of his work had been done, in 1880. He became director of the Museum of National History of Strasbourg in 1839.

12. *Williamson.*—In Mr. W. C. Williamson we have a third of the line of eminent British paleobotanists, whose chief attention has been directed to the study of the internal structure of Carboniferous plants, and the one who at the present time unquestionably stands at the head of this school of investigators. If we include his paper "On the Origin of Coal," published in the report of the British Association for 1842 (Part II, pp. 48, 49), his place would be where we have assigned him, but his special work upon the plants themselves seems not to have commenced until 1851, and then to have been more or less interrupted until 1868, since which time it has been incessant, culminating in his great work "On the Organization of the Fossil Plants of the Coal Measures," which runs through so many volumes of the "Philosophical Transactions." Of the merits of this work, as of all of this author's investigations, it is certainly unnecessary to speak here.

13. *Lesquereux.*—Mr. Leo Lesquereux of Columbus, Ohio, is one of those acquisitions which America has so often made at Europe's expense when political turmoils arise there and make liberty dearer even than country. He was of that little band, which also included Agassiz and Guyot, who were compelled to abandon Switzerland in 1847 and 1848, on the occasion of the breaking up of the Academy of Neuchâtel and the coming into power of the so-called Liberal party. His ancient family name was Lescure, afterwards Lescurieux, and finally Lesquereux, and his immediate ancestors were French Huguenots. He was born November 18, 1806, at Fleurier, canton of Neuchâtel. His father was a manufacturer of watch springs and endeavored to teach him that business, though, since his health was somewhat delicate, his mother preferred to prepare him for the ministry; but Science had marked him for her own, and no power could withdraw him from nature. With a taste for plants in general, he was led by circumstances first to the study of mosses, then naturally to that of peat, and lastly to that of fossil plants. The government of Neuchâtel was then greatly interested in the protection of peat bogs on account of the difficulty of procuring fuel for the poor, and offered a prize (a gold medal of 20 ducats) for the best memoir on the formation and preservation of peat. Lesquereux competed and won the prize. His prize memoir [12] gained a wide reputation, was extensively copied, and is still quoted as one of the best on the subject.

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[12] Quelques recherches sur les marais tourbeux en général. Mémoires de la Société des sciences naturelles de Neuchâtel, Tome III, 1845. (See summary in the Archives des sciences phys. et nat. de Genève, Tome VI, p. 154.)

The connecting link between this study and that of fossil plants was supplied two years later, when he wrote a short paper "Sur les plantes qui forment la houille."[13]

On his arrival in America he studied the coal formations of Ohio, Pennsylvania, Illinois, Kentucky, Arkansas, and other States, and his reports appear in those of the geological surveys of all of these States. Especially important are those upon the coal flora of Pennsylvania. The first of these appeared in the second volume of the report of H. D. Rogers, in 1858, consisting of some quite elaborate "General Remarks," and a "Catalogue of the Fossil Plants which have been Named or Described from the Coal Measures of North America." This is accompanied by twenty-three excellent plates. But this was a mere beginning, for when the second geological survey of Pennsylvania was undertaken Mr. Lesquereux was employed to work up the coal flora, which appeared in 1880 in a volume of text and an atlas, the most important work on carboniferous plants that has been produced in America. A third volume, supplementary to these, has just been issued.

In 1868 Mr. Lesquereux began the study of the floras of later formations in the West, and contributed an important paper on the Cretaceous leaves of Nebraska to the "American Journal of Science."[14] Dr. F. V. Hayden employed him to work up the collections of his surveys of the Territories, and important papers on the subject appeared in the annual reports of the survey for 1870, 1871, 1872, 1873, and 1874. In the last of these years appeared his "Cretaceous Flora," forming Volume VI of the quarto reports. In 1878 the seventh volume of these quarto reports was published, a still larger work, devoted to what he called the "Tertiary Flora," though a very large proportion of the species were from the Laramie Group. The eighth of these volumes will also be by Mr. Lesquereux, and will consist of a thorough revision of the entire Cretaceous and Tertiary floras of North America. Mr. Lesquereux is still living, and though infirm with age is actively engaged in bryological and paleontological studies.

14. *Dawson.*—To Sir J. W. Dawson is due the greater part of the knowledge we possess concerning the vegetable paleontology of Canada and the British North American provinces in general. His numerous papers, running back as far as 1845,[15] are almost exclusively confined to the description and illustration of material from this part of the world, and all except a few recent ones relate to the older formations of the East.

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[13] Archives des sciences physiques et naturelles (Bibliothèque universelle), Tome VI, 1847, pp. 158–162. Genève.

[14] On Some Cretaceous Fossil Plants from Nebraska. Am. Journ. Sci., 2d series, Vol. XLVI (July, 1868), pp. 91–105.

[15] His paper "On the Newer Coal Formation of the Eastern Part of Nova Scotia" (Quart. Journ. Geol. Soc. Lond., Vol. I, 1845, pp. 322–330) merely names a few genera occurring there, but his "Notices of Some Fossils Found in the Coal Formation of Nova Scotia" (l. c., Vol. II, 1846, pp. 132–136), giving his views on Sternbergia, attracted immediate attention.

His reports upon "The Fossil Plants of the Devonian and Upper Silurian Formations of Canada," upon "The Fossil Plants of the Lower Carboniferous and Millstone Grit Formations of Canada," and upon "The Fossil Plants of the Erian (Devonian) and Upper Silurian Formations of Canada" are monographs of especial value. A geologist rather than a botanist, he has done excellent service, not only in elucidating the important problems of Acadian geology, but also in demonstrating the value and legitimacy of the evidence furnished by vegetable remains.

Dawson was born at Pictou, Nova Scotia, in the year 1820, and though educated at Edinburgh, he returned to his native country and has devoted his whole life to the study of its geology and paleontology. He is a fellow of the Royal Society of London and of the Geological Society, and has long honored the well-known post of Principal of McGill University, Montreal. We learn with great satisfaction, though almost too late to be fittingly mentioned here, that the order of knighthood has just been conferred upon him on the occasion of the meeting of the British Association in his adopted city.

15. *Heer.*—The numerous obituary notices that have so recently appeared in all the scientific journals render it unnecessary to give in this place any extended biographical sketch of this eminent savant. He was born at Glarus, Switzerland, in 1809, and died at Lausanne in 1883, after having long filled the chair of botany in the University of Zürich. Vegetable paleontologists note with some surprise that he is mentioned by his biographers chiefly as an entomologist,[16] and naturally wonder how great must have been his eminence in that department to overshadow his vast and invaluable labors in the domain of fossil plants.

He commenced writing upon this latter subject in 1846.[17] The first volume of his great work, "Flora tertiaria Helvetiæ," appeared in 1855, the second in 1856, and the third in 1859. The exceedingly great care, accuracy, and thoroughness with which this *chef d'œuvre* of science was executed, especially in the matter of illustration, is a marvel to contemplate. Nothing comparable to it had appeared before, and nothing equal to it has appeared since. He became interested in the fossil floras of remote parts of the globe, and among the first of his memoirs on such subjects was one that may be found in the Proceedings of the Academy of Natural Sciences of Philadelphia for 1858 (pp. 265–266), on the "Fossil plants of the Lower Cretaceous beds of Kansas and Nebraska." He also figured the "Phyllites Crétacées du Nébraska," collected by Marcou and Capellini.[18] In 1866 his memoirs upon the fossil floras of the Arctic regions commenced to appear, and to this fertile subject he devoted the greater part of the rest of his life. The first volume of his "Flora

[16] "Science," Vol. II, p. 583, 1883; "Nature," Vol. XXVIII, Oct. 25, 1883.

[17] The first paper of which there is a record is the one "Ueber die von ihm an der hohen Rhone entdekten fossilen Pflanzen," which appeared in the Verhandlungen der Schweizerischen Gesellschaft for 1846, pp. 35–38.

[18] Neue Denkschriften der Schweizerischen Gesellschaft der Naturforscher, Zürich, 1866. Mém. I.

fossilis arctica" appeared in 1869, the second in 1871, and the remaining five at intervals of about two years, the seventh and last coming out in the year of the author's death. With the exception of the first volume, this colossal work consists entirely of a compilation of more or less independent memoirs, which were published as fast as prepared in various scientific periodicals in several languages, and which are merely put together into volumes of convenient thickness. Each memoir has its own independent pagination, generally that of the volume of Transactions in which it originally appeared, all of which renders it very inconvenient for consultation, but cannot detract from its great value as a reservoir of facts.

Bunbury.—It may be doubtful whether the paleobotanical works of Sir Charles Bunbury are of sufficient importance to entitle him to enumeration among the principal cultivators of that science, but they have certainly been quite numerous and covered a wide range of subjects, both geographically and botanically. He began by elaborating certain material from the United States[19] and the British provinces,[20] collected by Sir Charles Lyell and Dr. Dawson, and was the first to recognize the merits of the views of the latter respecting the fossils known as *Sternbergia* from the coal fields of Sydney. But he also worked up material from France, Portugal, Madeira, and India, as well as from Yorkshire and other parts of England. His investigations have been chiefly confined to carboniferous fossils, but in a quite recent work[21] he has published some interesting views on the subject of nervation which may prove of value.

17. *Massalongo.*—Abramo Massalongo, the first of the Italian school of paleobotanists whose work claims our attention here, commenced publishing in 1850,[22] and continued with great activity until 1861. He confined his investigations almost exclusively to material from his own country, and contributed more to the elucidation of the fossil floras of Italy than any other author. The number of his papers is very large, considering the comparatively short period during which he was permitted to work, and an unusually large percentage of them are monographs of considerable size. His greatest work, for which Scarabelli contributed the stratigraphical part, was his "Studii sulla flora fossile e geologia stratigraphica del Senigalliese," Imola, 1859, but of which

[19] On some remarkable Fossil Ferns from Frostburg, Md., collected by Mr. Lyell. Quart. Journ. Geol. Soc., 1846, Vol. II, pp. 82–91. Observations on the Fossil Plants of the Coal Field of Tuscaloosa, Ala., etc. Silliman's Journal, 1846, pp. 228–233. Description of Fossil Plants from the Coal Field near Richmond, Va., Quart. Journ. Geol. Soc., 1847, Vol. III, pp. 281–288.

[20] Notes on some Fossil Plants, communicated by Mr. Dawson, from Nova Scotia. Quart. Journ. Geol. Soc., 1846, Vol. II, pp. 136–139. On Fossil Plants from the Coal Formation of Cape Breton, Nova Scotia. *Ibid.*, 1847, Vol. III., pp. 433–428, and numerous similar memoirs.

[21] Botanical Fragments. London, 1883.

[22] See his Schizzo geognostico sulla Valle di Progno (Preludium Floræ fossilis Bolcensis), Verona, 1850. Collett. dell' Adige, 14 sett., 1850.

his "Synopsis floræ fossilis Senogalliensis," Verona, 1858, forms an integral part, having been prepared from the plates of the former, to which reference is constantly made. This work is thoroughly illustrated by forty-five large quarto plates of well executed but not very well printed figures, and is one of the most important contributions to the Tertiary flora of Europe. It virtually and fittingly closed the too short but perhaps too active career of one of Italy's most talented scientists

18. *Ettingshausen.*—Since the death of Oswald Heer the great merits of Baron von Ettingshausen's paleobotanical researches, always highly appreciated, have seemed to command especial attention. Beginning this career simultaneously with Massalongo in the year 1850,[23] he has had the advantage over the Italian savant of being permitted to continue it uninterruptedly under the most favorable auspices down to the present time. He immediately began his studies in the Tertiary flora of the Austrian Monarchy, and published the Tertiary Flora of Vienna in 1851. His "Beiträge zur Flora der Vorwelt," "Proteaceen der Vorwelt," and numerous lesser papers appeared in the same year. From the number of important papers that appeared during 1852 and 1853 it is clear that he must have been very active, entering as he did into the study of Paleozoic and Mesozoic floras, as well as continuing his work on the Tertiary plants. It was, however, in 1854 that he laid the foundation for that deserved renown which he now enjoys in taking up under such extraordinarily favorable conditions the investigation of the true principles of nervation in dicotyledonous leaves. The process of nature-printing, or physiotypy (*Naturselbstdruck*), had been invented in the Austrian imperial court and state printing-office by Auer and Worring, and Ettingshausen at once perceived its special applicability to the science of botany. Recognizing the vast importance of this discovery to paleobotany he obtained permission to employ the new method and proceeded to prepare his first monograph "Ueber die Nervation der Blätter und blattartigen Organe bei den Euphorbiaceen mit besonderer Rücksicht auf die vorweltlichen Formen,"[24] which he followed up with a similar memoir, "Ueber die Nervation der Blätter der Papilionaceen.[25] To the first of these memoirs was prefixed a brief synopsis of the classes of nervation found in euphorbiaceous leaves. Availing himself of the efforts in this direction which had been previously made by Leopold von Buch,[26] Bianconi,[27] and others (he seems

[23] No less than four of his papers appeared in that year, one in the Sitzungsberichte of the Vienna Academy, one in the first volume of the Austrian Geological Jahrbuch, and two in the sixth volume of Haidinger's Collections of Memoirs.

[24] Sitzungsberichte d. Akad. d. Wiss. Wien. Bd. XII, 1854, pp. 138–154, Pl. I–XVII.

[25] *Loc. cit.*, pp. 600–663, Pl. I–XXII.

[26] Ueber die Blattnerven und ihre Vertheilung. Monatsbericht der Berliner Akademie der Wissenschaft, 1852, pp. 42–49, with plate.

[27] Giuseppe G. Bianconi. Sul sistema vascolare delle foglie, considerato come carattere distintivo per la determinazione delle filliti. N. Ann. d. Sc. Nat. Bologna, 1838, Ann. I, Tom. I, pp. 343–390, Pl. VII–XIII.

not to have been acquainted with De Candolle's "Organogénie"), he proposed a classification and terminology, which, so far as they went, Heer was willing to adopt,[28] and which are in common use by paleobotanists at the present time. In 1855 Ettingshausen and Pokorny received instructions to prepare a work for the Paris Exposition to be held in 1867 that should thoroughly illustrate the application of the nature printing process to the science of botany. The result was that immense and astonishing production entitled "Physiotypia plantarum Austriacarum," with its six enormous volumes of most exquisite plates, not only illustrating the leaves of the trees and shrubs, the flowers with their petals, sepals, stamens, and pistils, but the entire plants wherever within the ample limits of size, and these stand forth from the plates in actual relief like a veritable *hortus siccus*. This grand success was followed up by various monographs upon the nervation of certain important orders, as the Celastrineæ, Bombaceæ, Gramineæ, etc. Aided further by this magic process he commenced in 1858[29] a series of works illustrating the skeletons only of leaves, the most important of which is his "Blattskelette der Dykotyledonen," which appeared in 1861. The way thus cleared for the successful study of the Tertiary floras of the world, Ettingshausen, from this time on, has continued his important investigations in this field, and each year our knowledge of fossil plants is increased and extended by his enlightened contributions. It would carry us quite beyond our limits to attempt an enumeration here even of the most important of these memoirs, but we cannot complete our brief sketch of Ettingshausen's invaluable labors without a passing reference to such productions as his Flora of the Tertiary basin of Bilin, his Cretaceous Flora of Niederschöna, his Floras of Wetterau, Steiermark, Radoboj, Sagor, etc. Coupled with his great powers of accurate observation and strictly scientific method of investigation, Ettingshausen displays an unusually broad grasp of the deeper problems which paleobotany presents and has undoubtedly been for many years far in advance of all his contemporaries in this field in correctly apprehending and announcing the true laws of phytochorology and plant development.

Baron von Ettingshausen was born in 1826 at Vienna, and is a member of many learned societies and scientific bodies.

19. *Newberry*.—Dr. John Strong Newberry, of the School of Mines, Columbia College, New York, one of the most eminent American geologists, was born at New Windsor, Conn., December 22, 1822, and graduated at Western Reserve College in 1846. Two years later he took the degree of M. D. from Cleveland Medical College, Ohio. Before commencing the practice of his profession at Cleveland, in 1851, he spent two years in Europe. On his return opportunities soon presented them-

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[28] Flora Tertiaria Helvetiæ, Band II, pp. 2–6.

[29] The first was his "Blattskelette der Apetalen," Wiener Denkschriften, Band XV, 1858, pp. 181–272, with fifty-one plates.

selves for joining parties of exploration in the far West, and he finally became a member of the celebrated Ives Exploring Expedition. With a special fondness for geology and mining he combined a deep interest in paleontology, in all of which specialties he has distinguished himself. The Carboniferous formation of Ohio had early interested him much, and especially the vegetable remains found embedded in it, and as far back as 1853 we find him reading papers before the American Association, "On the structure and affinities of certain fossil plants of the Carboniferous era," and "On the Carboniferous Flora of Ohio, with descriptions of fifty new species of fossil plants."[30] In 1859 he reported upon the fossils, including plants, of the Macomb Exploring Expedition,[31] in 1861 those of Lieutenant Ives's Expedition,[32] and in 1863, those of the Northwest Boundary Commission.[33] Probably the most important of his paleobotanical memoirs thus far published was his "Notes on the Later Extinct Floras of North America," which appeared in the Annals of the New York Lyceum of Natural History for April, 1868. No plates accompanied this memoir, but a large number of the plants described had been figured by Dr. Newberry, which he had expected to be published by the Geological Survey of the Territories, but none appeared until 1878.[34] He has, however, been more or less constantly engaged since that time in figuring the large collections which have been reaching him each year at the School of Mines, and over one hundred plates have, up to the present writing, been prepared, most of which are printed and awaiting the text of a large work which will be published by the United States Geological Survey.

20. *Schenk.*—Hofrath Dr. August Schenk, professor of botany at the University of Leipsic, was born at Hallein, Upper Austria, in 1815, and held the chair of botany at Münich and Würzbach before being called to that of Leipsic. His paleobotanical researches have been chiefly directed towards a little known horizon lying between the Buntersandstein and the Lias, and upon this dark region they have shed a flood of light. His earlier papers[35] related to fossil plants from the Keuper, chiefly collected in the vicinity of Bamberg and Bayreuth, and, in addition to material collected by himself and Dr. Kirchner, he elaborated that brought together by the Count of Münster, but later he turned his attention to some rich plant beds overlying these strata and situated intermediate between them and the Lias. It is upon this narrow horizon

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[30] Proceedings, pp. 157-166.

[31] Report of the Expedition, pp. 142-148, Pl. IV-VIII.

[32] Report upon the Colorado River of the West, by Lieut. Joseph C. Ives, Washington, 1861, pp. 129-132., Pl. III.

[33] Boston Journal of Natural History, Vol. VII, 1863, pp. 506-524.

[34] Illustrations of Cretaceous and Tertiary plants. Washington, Government Printing Office, 1878.

[35] The earliest seems to have been "Ueber einem in der Keuperformation bei Würzburg aufgefundenen fossilen Farnstamm (Chelepteris strongylopeltis). Verhandlungen der Würzburger physicalisch—medicinschen Gesellschaft, Band VIII, 1858, pp. 212-216.

that he has bestowed the closest attention, and his final monograph upon the subject, which, dropping the term *Rhetic*, he has entitled "Die fossile Flora der Grenzschichten des Keupers und Lias Frankens," is a very valuable contribution to paleobotany. Still later (1868), he took up the Muschelkalk beds of Recoaro, first noticed by Catullo,[36] but treated by a number of authors, and produced a finely illustrated little work "Ueber die Pflanzenreste des Muschelkalkes von Recoaro." Besides his "Beiträge zur Flora der Vorwelt" in the *Palæontographica*, and numerous minor contributions, Dr. Schenk has elaborated the fossil plants for Baron Richthofen's "China,"[37] and, since Schimper's death, has gone on with the vegetable department of Zittel's "Handbuch der Paläontologie."[38]

21. *Saporta.*—The death of Professor Heer broke up the illustrious trio of continental paleobotanists who had so long taken the lead in the study of the fossil plants of the Tertiary formation—Heer, Ettingshausen, and Saporta. The two that remain are of more nearly the same age, and in many respects admit of a more ready comparison; still their fields of labor are so well separated that no conflict can occur in their operations, and both seem likely to continue uninterrupted for many years their already extensive investigations.

The Marquis (until a year ago Count) Gaston de Saporta, was born in the year 1823 at Saint Zacharie, department of Var, in Provence, France, and it was in the near vicinity of his native place that he first began[39] his paleobotanical studies, and to the thorough illustration of the fossil botany of Provence he has always devoted his best energies. His "Etudes sur la végétation du sud-est de la France à l'époque tertiaire,"[40] begun in 1863, has thus far remained his *chef d'œuvre*, and most of the localities treated in this work are situated in Provence. In 1873 he published "La revision de la flore fossile des gypses d'Aix," which was practically a revision of the "Etudes."[41] Among his other more important works on Cenozoic floras may be mentioned his "Prodrome d'une flore fossile des travertins de Sézanne,"[42] in which the flora of the Eocene, or Paleocene, as he terms it, is better set forth than in any other work, and his "Essai sur l'état de la végétation à l'époque des marnes

[36] Nuovi annali di scienzi natur. di Bologna, serie II, Tom. V. 1846, pp. 81–107 (see p. 106).

[37] Band IV, pp. 209–269, 284–288, Pl. XXX–LIV.

[38] II. Band, III. Lieferung.

[39] Note sur les plantes fossiles de la Provence, Lausanne. Bulletin de la Société vaudoise des sciences naturelles, Tome VI, 1860, pp. 505–514. Examen analytique des flores tertiaires de Provence, Zürich, 1861.

[40] Annales des sciences naturelles—Botanique—4e série, tomes XVI XVII, XIX: 5e série, Tomes III, IV, VIII, IX, 1861–'68.

[41] *Loc. cit.*, 5e série, Tome XVIII.

[42] Mémoires de la Société géologique de France, Tome VIII, 1865, pp. 289–438, Pl. XXII–XXXVI.

heersiennes de Gelinden,"[43] in which, as in his "Recherches sur les végétaux fossiles de Meximieux,"[44] he was assisted by Prof. A. F. Marion. But Saporta's contributions do not all relate to the Tertiary. Of nearly equal importance have been his studies in the Jurassic flora of France.

The three volumes of his "Plantes jurassiques,"[45] which have already appeared, with accompanying atlas, constitute, without any doubt, the most exhaustive treatise upon the vegetable paleontology of that horizon that has thus far been produced. Its value is by no means confined to the light it throws upon the Mesozoic flora of France. The manner in which the determinations are supported by comparison with other fossil and with living floras, renders the work a thoroughly general one. Indeed no better treatise exists on the histology of coniferous stems and on the classifications of the Coniferæ in general than is to be found in the introduction to the third volume of this work. Besides numerous other minor descriptive papers and memoirs of greater or less length and importance on fossil plants, Marquis Saporta has written two interesting popular books on the subject. That entitled "Le Monde des Plantes avant l'apparition de l'homme," which appeared in 1879, is unquestionably the best popular treatise in this branch of science. The first volume of the work on "L'evolution du règne végétal," confined entirely to a study of the Cryptogams from the point of view of evolution, appeared in 1881 as one of the International Scientific Series, though it seems never to have been translated into English. In this work Professor Marion was associated. Other volumes showing the evidence of phenogamous plants for the doctrine of evolution are anxiously looked for. Saporta has long been a strong supporter of this class of views, and his writings display a broad and enlightened spirit.

22. *Carruthers.*—The subject of this sketch was born at Moffat, Scotland, and educated in Edinburgh. In 1859 he entered the British Museum as assistant in botany, and became keeper of the department of botany in 1871. He began his paleobotanical work by re-editing Lindley and Hutton's "Fossil Flora of Great Britain," and is understood to be now preparing a supplement to it. During this time he has been constantly contributing articles upon various points connected with his investigations. The number of such papers is very large and their merit so great that his title to a place in the present enumeration will not probably be disputed. Although pursuing somewhat the same line of investigation as the other British paleobotanists, he still has given himself a much wider field. He has not limited his researches to the Paleozoic, but has made incursions into the Mesozoic and even into the Tertiary. Fossil fruits have formed a favorite study for him, and his investigations have widely

[43] Mémoires couronnés de l'Académie des sciences de Belgique, Bruxelles, 4e édition, Tome XXXVII, No. 6, 1873.

[44] Archives du Muséum d'histoire naturelle de Lyon, 4e livraison, 1876, p. 131.

[45] Paléontologie française. Série 2. Végétaux, 1873, 1875, and 1876–1883.

expanded this field of knowledge. Mr. Carruthers was elected a fellow of the Royal Society in 1871.

In terminating this enumeration here it is evident that the limit of space and not of matter has been the motive. The aim has been rather to consider the great names in the past history of the science than to venture an estimate of the worth of present workers in it, and if a number of living representatives have been named it is because their services have already been so great as to have given a special color to that history and to afford a safe basis for judging of their future work. With most of the many present devotees of paleobotany this last condition at least does not exist, and the fear of coming far short of doing them justice, at least in the estimation of their future biographers, has deterred me from introducing their names into this brief *résumé*.

But aside from this class no little difficulty has been encountered in choosing from among the older workers, and although in many cases no two would agree where the line should be drawn, it is by no means improbable that some obvious mistakes have been made, and that names which have been omitted should have been substituted for some that have been mentioned. Defects of this class, and also those of various other kinds, may, however, be partially remedied in the treatment of the next division of the subject, in which the field will be less restricted in this respect, and we shall look more especially to the work done than to the men who have done it.

B.—SKETCH OF THE EARLY HISTORY AND SUBSEQUENT PROGRESS OF PALEOBOTANY.

1. THE PRE-SCIENTIFIC PERIOD.

Science often has its origin in wonder at unexplained phenomena, and there is no science of which this is more true than of paleontology. Nearly all the early writers openly avow that they have been chiefly spurred on to undertake and carry on their investigations by an "eager curiosity"[46] respecting the objects they were treating, and the first collections of such objects were looked upon simply as curiosities, while what have since become the greatest scientific institutions in the world sometimes betray their origin by perpetuating the original names expressive of their sense of wonder.[47]

No greater objects of wonder have presented themselves to man's consideration than the fossils which from the earliest times have been observed in different parts of the earth's crust. The efforts of the rational mind to interpret these phenomena, although they may seem amusing to the unthinking, are really of deep philosophic and even scientific interest. It may surprise some to learn that the conclusions

[46] Parkinson's Organic Remains of a Former World, 1804, p. v.

[47] For example the great Academia Cæsarea Leopoldino-Carolina Naturæ Curiosorum, founded in 1670 at Frankfort-on-the-Main.

reached by the ancients were far more correct than those drawn twelve to sixteen centuries later, from much more ample data. Strabo, Xenophanes, Xanthus, Eratosthenes, and even Herodotus believed that the fossil shells they had seen once contained living animals, and that in process of time they had been turned into stone. They further concluded that the mountains in which they were found imbedded were once under the sea. These doctrines were known to the Romans, and of their popular acceptance by the cultivated classes we have evidence in the familiar lines of Ovid's "Metamorphosis."[48] This view was also shared by Pliny and other post-Augustan writers, and even Tertullian[49] did not perceive its inconsistency with Christian philosophy, which caused its complete rejection during the next thirteen centuries. Of the fact of this long stagnation not only in this but in nearly all other departments of science there is no question,[50] but as to its cause there are differences of opinion which this is not the place to discuss. The doubtless charitable attempt, however, to throw the responsibility back upon Aristotle and his famous doctrine of *generatio æquivoca*,[51] merely because that doctrine was found more in harmony with the cosmogony which became ingrafted upon those sombre ages, should, in the single interest of historic truth, be condemned, while it is too late in the scientific epoch to make it either necessary or prudent to hesitate in confessing that the reasoning powers of man were virtually destroyed during that period by the almost universal and thoroughly honest acceptance of a false cosmogony.[52]

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[48] "Vidi ego, quod fuerat quondam solidissima tellus
Esse fretum, vidi factas ex æquore terras,
Et procul a pelago conchæ jacuere marinæ,
Et vetus inventa est in montibus ancora summis."
(Lib. XV, 262.)

[49] "Mutavit et totus orbis aliquando, aquis omnibus obsitus; adhuc maris conchæ et buccinæ perigrinantur in montibus, cupientes Platoni probare etiam ardua fluitasse." (De Pallio, II.)

[50] "During the next thirteen or fourteen centuries fossil remains of animals and plants seem to have attracted so little attention that few references are made to them by writers of this period. During these ages of darkness all departments of knowledge suffered alike, and feeble repetitions of ideas derived from the ancients seem to have been about the only contributions of that period to natural science." (Address of Prof. O. C. Marsh as president of the American Association for the Advancement of Science, 1879. "Proceedings," Vol. XXVIII, p. 4.)

[51] "In den darauf folgenden Zeiten verdrängte die aristotelische und nachherige scholastiche Philosophie die Naturkunde, wobei man natürlich auch die Petrefakten fast gänzlich vernachlässigte und sie fast nur erwähnte, um die ungegründete Lehre des Aristoteles von der *generatio æquivoca* alsbald auch auf sie anzuwenden." (Göppert, Systema Filicum Fossilium, p. 4.)

[52] "Cette science eut beaucoup plus de peine à se développer que les autres sciences naturelles, telles que la physique et la chimie, car elle rencontra tout d'abord une opposition religieuse qui en entrava longtemps les progrès. L'orthodoxie biblique craignant que la science ne s'écartât trop des traditions de la Genèse, interdisait aux savants l'étude indépendante des fossiles, dans lesqueles elle ne voyait que les débris des êtres anciens détruits par le déluge de Noë." (Schimper, Traité de paléontologie végétale, Tome I, p. 6.)

It is only in so far as they relate to fossil plants that these general considerations can be entered into here, although so closely are all branches of paleontology blended in those early and, as it were, undifferentiated stages of their historical development that too strict a construction of this rule might exclude matter which has an important bearing upon paleobotany. The special science, however, must be regarded as very much younger than the general one. Indeed, while there is no doubt that the ancients were familiar with several kinds of animal fossils, particularly shells and corals, it is generally believed that they were wholly unacquainted with any form of vegetable petrifaction.[53] This complete ignorance seems to have continued throughout the middle ages down to the thirteenth century.

It is certainly surprising that so common an object as a piece of petrified wood should never have been observed by intelligent people inhabiting limestone regions like those of Greece and Italy, and it is hard to believe that this was really the case. It is more reasonable to suppose that such things were sometimes seen and wondered at by rustics, but that for some reason they escaped being recorded; or they may have been recorded in some work that has failed to come down to us, like the two lost books of Theophrastus.

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[53] "D'empreintes végétales ou de débris végétaux pétrifiés, nulle mention chez les anciens." (Schimper, *loc. cit.*, p. 1. See also Brongniart, Histoire des végétaux fossiles, Tome I, p. 1; Sprengel, Commentatio de Psarolithis, p. 7; Göppert, Syst. Fil. Foss., p. 8.)

The following are among the passages most commonly quoted in support of the opposite view:

"Palmati [lapides] circa Mundam in Hispania, ubi Cæsar dictator Pompeium vicit, quoties fregeris." (To the word "palmati" is attached the following foot-note: "Qui palmæ intus fracti referant.") (Plinius, Nat. Hist., XXXVI, 29. Delphin Classics, 111, Pliny, 9, p. 4749.)

"In Ciconum flumine, et in Piceno lacu Velino lignum deiectum, lapideo cortice obducitur, et in Surio Colchidis flumine, adeo ut lapidem plerumque durans adhuc integat cortex. Similiter in Silaro, ultra Surrentum, non virgulta modo immersa, verum et folia lapidescunt, alias salubri potu ejus aquæ. In exitu paludis Reatinæ saxum crescit." (*Loc. cit.*, II, 106.)

"Syringitis stipulæ, internodio similis, perpetua fistula cavatur." (*Loc. cit.*, XXXVII, 67.)

"Qui navigavere in Indos Alexandri milites frondem marinarum arborum tradidere in aqua viridem fuisse, exemptam sole protinus in salem arescentem. Juncos [truncos] quoque lapideos perquam similes veris per littora," etc. (Theophrastus, *loc. cit.*, XIII, 51.)

"Quarti generis elatiten vocari quamdiu crudus sit: coctum vero militen, utilem ambustis, ad omnia utiliorem rubrica." (*Loc. cit.*, XXXVI, 38.)

"Dryites e truncis arborum: hæc et ligni modo ardet." (*Loc. cit.*, XXXVII, 73.)

Consult also, Theophrastus, *Περι Λιθων*, Sect. XXIX; Strabo, Geographica, Lib. XVI; and Pausanias, Græciæ Descriptio, Lib. I, cap. 43.

All these passages have, however, been carefully studied, and the conclusion reached that they refer only to stones resembling trunks, fruits, etc., to madrepores, to incrustations, or other mineral substances, and not in any case to real petrifactions.

Brongniart has offered an apology for the ancients,[54] on the ground that no coal mines occur in Greece or Rome, and that Spain, Northern Africa, and Western Asia, with which alone they were acquainted, are all equally wanting in that formation; and he very truly remarks that the knowledge of fossil plants really began simultaneously with the use of coal, as the destruction of the forests of Western and Northern Europe forced the growing population to discover some substitute for wood as fuel. This is quite true so far as coal plants are concerned, and somewhat so for all those fossils which are only exposed by mining, yet when we consider the extensive public works that were carried on by the Romans, in connection with the large number of rich beds of fossil plants now known in Italy, Dalmatia, Eubœa, and with the petrified forests of northern Egypt and other countries of the Roman Empire, some other explanation is certainly needed to account for the silence of ancient literature upon the subject. This is to be found in the highly artificial character of their civilization, and the little interest taken in or attention paid to the phenomena of nature around them. This state of society can be easily imagined by eliminating from our own society the very minute fraction of the citizens of any modern country who ever observe or reflect upon natural objects or phenomena. In any large city these can almost be counted upon the fingers, and this could then be done for the whole Roman Empire, while during the succeeding ages even these few were wanting, and the flicker that Pliny kindled upon the dying embers of Grecian learning was allowed to go entirely out.

It was long supposed that Agricola[55] was the first to make unequivocal mention of petrified wood, but a passage has been found in Albertus Magnus,[56] which leaves no doubt that his attention had been definitely drawn to this subject, and which carries it back to the thirteenth century. This passage, however, seems to have attracted no attention, and it was only after Agricola had twice[57] expressed his views on the subject that other writers took it up. Matthiolus in his letter to Bauhin (1564), and Gesner[58] (1565), described specimens which came into their possession. A long discussion followed as to the true nature of these petrifactions and all kinds of theories were put forward. Already for

[54] Histoire des végétaux fossiles, Tome I, p. 1.

[55] Georgius Bauer Agricola. De natura fossilium, 1558, Lib. VII, pp. 324, 328.

[56] "Similiter autem ligna jacentia in quibusdam aquis et maribus convertunt in lapides et retinent figuram lignorum. Et aliquàndo natæ plantæ in aquis et maribus illis ita sunt vicinæ lapidum naturis quod ad modicum exiccatæ in aëre, lapidum formam assumunt," etc. (Beati Alberti Magni De mineralibus. Tractatus I. Caput VII. Opera, Tom. II, p. 216, Lugduni, 1651.)

[57] "De ortu et causis subterraneorum. Lib. III. In De re metallica, Basileæ, 1657, p. 507. Arbores * * * lapidescunt * * * tum sic in saxa commutatæ, ut suus cujuscunque; truncus et rami mox sub aspectum veniant: cortex a ligno non difficiliter internoscantur."

[58] Conrad Gesner: De rerum fossilium, lapidum, et gemmarum maxime figuris et similitudinibus. Tiguri, 1565. (See cap. ix, fol. 125, f. 1.)

centuries had the discussion of petrifactions in general been raging and the discovery of petrified wood only added new complications to an old controversy. Enlarging upon Aristotle's doctrine of spontaneous generation, the scholastic writers had affirmed that it was as possible for stones of any required form to produce themselves as for living animals and plants. Avicenna in the tenth century had proposed his *vis lapidifica*, and Albertus Magnus in the thirteenth his *virtus formativa*. Bauhin[59] predicated a spirit of the Universe, or Archæus, while Libavius[60] held that fossils sprang, like living things, from a true germ or seed. Balthasar Klein obtained a specimen, one side of which was stone, the other coal, and this excited intense curiosity. He sent the specimen to Matthiolus, who studied it and came to the conclusion[61] that coal was the third or final step in the process of transmutation, and that just as wood turned into stone so stone in turn was transformed into coal. Klein's own views were much more rational. The discovery in the mines of Joachimsthal of a petrified trunk with the bark on added to the interest already aroused on this subject and kept alive the discussion.

Thus far only petrified wood had been observed or considered, and although Johannes Kentmann,[62] in 1565, had given an account of some leaf impressions formed by incrustations of tufa, no mention of the remains of the foliar organs of plants in any true rock formation seems to have been made until 1664, when Johann Daniel Major published at Jena his "Lithologia curiosa, sive de animalibus et plantis in lapides versis." This work was so little known that whatever its merits it attracted no notice, and the subject of fossil plants in the sense now commonly understood remained practically untouched until the close of the seventeenth century.

In 1699 appeared at London Lhwyd's "Lithophylacii britannici Ichnographia,"[63] in which were not only described but figured with sufficient fidelity for identification a number of ferns from the coal measures of England. A period of great activity in this department of human observation, we can scarcely say science, followed the appearance of this work, but before attempting to follow the development from this point we may pause a moment to consider the history and progress of ideas which in all ages so largely formed the spur to observation and investigation.

With the discovery of fossilized leaves and fronds by Major and Lhwyd all the departments of paleontology had been opened to discussion, and in those early days discussion was the primary consid-

[59] De fontibus et balneis Bollensis.

[60] Hist. et invest. font. medic. ad Tubarin sub Rotembergo. P. III, Franc. ad Mœnum.

[61] Epistolæ ad Bauhin, III, pp. 141, 142, 1564.

[62] Nomenclatura rerum fossilium, etc. Tit. vi, Lapides. Tiguri, 1565, fol. 38.

[63] Eduardi Luidii Lithophylacii britannici ichnographia, sive lapidum aliorumque fossilium britannicorum singulari figura insignium * * * distributio classica. Londini et Lipsiæ, 1699. 8°. (See Tab. 4 & 5, Figs. 184*, 186, 188, 189, 190, 191, 197; see, also, two Annularias, Figs. 201 & 202, Tab. 5.)

eration. The end was then, as now with modern science, the ascertainment of truth, but the lesson had not yet been learned that to this end the accumulation and investigation of facts is the first and principal requisite.

The mystic views of Avicenna, Albertus, Bauhin, Matthiolus, and Libavius, already referred to, prevailed in varying forms throughout the seventeenth century. Sperling[64] (1657) advocated a stone-making spirit, or *aura seminalis*. Kircher[65] (1665) propounded his theory of *seminaria* of *corpuscula salina* as the true principle of petrifaction, and as really constituting the *vis lapidifica* or *spiritus architectonicus* which controls the action of the *succus petrificus*, or petrifying juice, in which he was followed more or less closely by Lachmund[66] (1669), Plot[67] (1677), Rhin[68] (1682), and Lhwyd[69] (1699), while others considered fossils as mere freaks of nature. Indeed, Camerarius[70] (1712) declared that in the beginning God had supplied these varied forms to the earth's interior the same as grass and herbage to its surface. This class of ideas, however, could with difficulty withstand the light of the accumulating facts after the commencement of the eighteenth century, and Lange's[71] attempt (1708) to demonstrate the germ theory proved one of the latest efforts of the kind. A modified Democritism, however, cropped out later, as seen in Dr. Arnold's (1733) investigation of the origin and formation of fossils, in which he postulated the existence of infinitesimal particles which were brought together in the creation of the world to form the outline of all the creatures and objects upon and within the earth, a work which found some favor on the continent and was translated into German in 1733.[72]

The theory which was destined to supplant these vague, unreal speculations and to prevail throughout the eighteenth century was what may be called the *flood theory*, viz., the idea that all or nearly all fossils consist of the débris of the life of the globe prior to the occurrence of the Noachian deluge, having been tossed and washed about in that great disturbance and then left stranded on or near the surface in the places where they now occur after the waters had retreated. This view may seem to us a poor substitute even for the worthless dreams which

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[64] John Sperling. Lithologia, quam sub præside viri, etc., examini submittit G. E. Wiegandus. Viteb., 1657.

[65] Athanasius Kircherus. Mundus subterraneus, Tom. II, Lib. VIII, Sect. I, Cap. III; Sect. II, Cap. I. Amsterdam, 1665.

[66] Friederich Lachmund. Oryctographia Hildesheimensis. Hildesheim, 1669.

[67] Robert Plot. Natural History of Oxfordshire, pp. 32, 33, 122, 124. Oxford, 1677.

[68] Lucas Rhin. Dissertatio de ebore fossili. Altdorf, 1682.

[69] Edward Lhwyd. *Loc. cit*

[70] Elias Camerarius. Dissertationes taurinenses physico-medicæ, Franof., 1712.

[71] Carolus Nicolaus Langius. Historia lapidium figuratorum Helvetiæ, p. 165. Venetiis, 1708. 4°.

[72] Theodore Arnold. Eine Untersuchung des Ursprungs und der Formirung derer Fossilien. Leipzig, 1733. 8°. I know this paper only from a mention of it by Schultze in his "Kräuterabdrücke im Steinreiche," S. 10.

had to make way for it, but when philosophically viewed it will be seen that it was really a decided advance upon those. This is clear when we remember that it involves the admission that the petrified forms represent true living forms that once inhabited the earth, which in so far is a scientific truth not embodied in any of the hypotheses thus far considered. He who reads the discussion of those times cannot fail to observe that it bears the stamp of all progressive controversy, in which a more realistic conception is confronting and overthrowing older idealistic ones.

The first intimation that remains of the Flood might be looked for seems to have come from Martin Luther, who in his commentary on the book of Genesis said he had no doubt that surviving indications of the Deluge might be found in the form of wood hardened into stone around the mines and smelting mills.[73] Alexander ab Alexandro in his "Geniales dies" (1522), also held this view, and was followed by Agricola (1546), Matthiolus (1564), Gesner (1565), and Imperatus[74] (1599). But this explanation made little or no headway against the fanciful theories of the time, and it was not until nearly a century later that the flood-theory, revived perhaps by a new edition of the work of Alexander ab Alexandro,[75] began to be reasserted and to take firm root. Dr. John Woodward, of London, who was a great collector of fossils, published a work in 1695[76] in which he held that all the solid parts of the earth's crust were loosened by the Flood and mingled promiscuously in its waters, and that at its close everything sank back to the surface according to its specific gravity, the remains of animals and plants assuming the positions in the respective strata in which they are now found petrified. Lhwyd, also, in the work already cited (1699) and other writings, gave countenance to this theory, which had thus acquired considerable respectability prior to the opening of the eighteenth century. But the greatest champion and expounder of the diluvian hypothesis was still to come in the person of Johann Jacob Scheuchzer, a brief sketch of whose life and work has already been given. His great work[77] appeared in 1709, in which he severely attacks all other theories and brings forward a mass of evidence in favor of his own which has proved of the greatest value to the progress of substantial knowledge and especially to that of paleobotany. It is not by this really useful and for its time important and remarkable work that, we fear, the name of

[73] "Und ich zweifele nicht, dass noch von der Sündfluth her ist, dass man an Oertern, da Bergwerck ist, oft Holtz findet, das schier zu Steinen gehärtet ist." Martin Luther's Gründliche und Erbauliche Auslegung des Ersten Buchs Mosis, Halle, 1739, Band I, col. 176.

[74] Ferrante Imperato. Dell' historia naturale. Napoli, 1590.

[75] Alexander ab Alexandro. Genialium Dierum, libri vi. Parisiis, 1539, Lib. v, Caput ix, fol. 120.

[76] John Woodward. An essay towards a natural history of the earth and terrestrial bodies. London, 1695. (See pp. 74 et seq.)

[77] Johann Jacob Scheuchzer. Herbarium diluvianum. Tiguri, 1709.

Scheuchzer is to-day chiefly known, but rather by the one in which he committed a most serious, and to us ridiculous, blunder in his zeal for his favorite dogma by describing the bones of a great salamander as those of a man who had been a witness of the Flood.[78] Scheuchzer did not accept Woodward's explanation, but believed that the animals and plants were buried in the slime and mud resulting from the Deluge and there underwent the process of petrifaction. He divided all the objects that he described into three classes—prediluvian, diluvian, and postdiluvian; but the first of these classes seemed to contain little more than dendrites and other minerals that he supposed to have come from the solid earth below the deposit left by the Flood, while the third class embraced such obviously recent incrustations as were clearly seen to be in process of formation in springs and certain streams. The bulk of the fossils described were set down as diluvian, and many of them were specially so designated in the appendix to the new edition published at Leyden in 1723.

Scheuchzer's work aroused a deep and widespread interest in the whole subject, and for many years collectors and writers vied with one another to discover additional evidences and describe new material. So supreme was his authority and so bold and forcible his reasoning that he carried conviction and inspired many disciples and followers. The diluvian theory became at once the prevailing doctrine, and nearly all the writers of the eighteenth century either openly espoused it or dared not oppose it. Mylius[79] (1709) accepted it, Büttner[80] (1710) saw signs and witnesses of it, Volkmann[81] (1720) labored to multiply proofs of it, Brückmann[82] (1727) and Da Costa[83] (1755) indorsed it, while even Walch[84] (1768) and Schröter[85] (1774) raised but a feeble voice against it. But the solid works of the two last-named authors and of a few others, and the now rapidly accumulating material for serious study combined with the few not always feeble protests, which, as we shall presently see, had all along, but especially in the later years, been raised against the Deluge hypothesis, now began to count heavily and to shake it at all points, and the last two decades of the eighteenth century were destined to see its collapse as rapid and complete as its rise had been sud-

[78] Idem. Homo diluvii testis et Θεοσκοπος. Tiguri, 1726. 4°.

[79] G. F. Mylius. Memorabilia Saxoniæ subterraneæ. Leipzig, 1709–1718.

[80] D. S. Büttner. Rudera Diluvii Testes, *i. e.*, Zeichen und Zeugen der Sünd-Fluth. Leipzic, 1710.

[81] G. A. Volkmann. Silesia subterraneæ. Leipzig, 1720, pp. 85, 86.

[82] Franc Ernest Brückmann. Magnalia Dei in locis subterraneis. Paris, 1727, fol.

[83] Emanuel Mendes da Costa. On the impressions of plants on the slates of coals. Phil. Trans. L, pp. 228-235, Pl. V. London, 1757.

[84] J. E. Immanuel Walch. Die Naturgeschichte der Versteinerungen zur Erläuterung der Knorrischen Sammlung. Nürnberg, 1768–1773.

[85] Johann Samuel Schröter. Vollständige Einleitung in die Kenntniss und Geschichte der Steine und Versteinerungen. Altenburg, 1774–1784. Versteinerungen des Pflanzenreichs, Bd. III, Kapitel I, pp. 99–238. (See especially pp. 106–109.)

den and vigorous in the first decade. For although Hugh Miller[86] was still able to find defenders of it as late as 1856, just as defenders of the geocentric theory can still be found, it was only among those who could have possessed no direct acquaintance with the real evidence, *i. e.*, the fossils themselves and the earth in which they were imbedded.

Having thus hastily reviewed the several unscientific theories that have at different periods been called in to explain the origin and nature of fossils in general and of fossil plants in particular, down to the close of the last century, we may now consider with equal brevity the history and progress of rational, and finally of scientific, ideas upon the same subject.

As already remarked the ancients, unfettered by any supposed revelation with which all facts must be made to accord, had not doubted that the objects found in the earth having the same form as those of animals found in the sea, represented such animals that had inhabited the sea at some former time, but how long ago they do not seem to have troubled themselves to inquire. Still there were not wanting those who speculated upon the origin of life on the earth, and Empedocles[87] actually stated the theorem, which is still lacking the data for complete demonstration, that vegetable life antedated animal life. How far the human mind proved capable of straying from this simple act of ratiocination we have already had occasion to see. It must not, however, be supposed that throughout the sixteenth, seventeenth, and eighteenth centuries, which we have been reviewing, no glimmer of reason ever made itself perceptible through the thick night of scholastic mysticism that hung over the contemplation of nature in whatever form. Sarayna[88] (1540), Moscardus[89] (1556), Balthasar Klein (1564), in the sixteenth; Columna[90] (1606) Scilla[91] (1670), Chioccus[92] (1622), Major[93] (1664), Hook[94]

[86] Hugh Miller. Testimony of the Rocks, etc. Boston, 1857. Lecture seventh.

[87] See C. Sprengel's Programma de Empedocle ad disput. inaugur. Goræ. Halæ, 1825.

[88] Torellus Sarayna. Museum Calceolarii, p. 407.

Idem. Bonanni Museum Kircherianum, p. 198.

Idem. Museum Moscardi, p. 172.

[89] Ludovico Moscardo. Note ovvero memorie del Museo del Conte Moscardo del medesimo descritte, Verona, 1556.

[90] Fabius Columna. Minus cognitarum rariorumque nostro coelo orientium stirpium Ecphrasis, etc. Romæ, 1606.

Idem. De purpura. Romæ, 1616, et Kiliæ, 1675. I have only been able to consult the edition of 1675.

Idem. De Glossopetris. In the last and also appended to the next.

[91] Angustinus Scilla. De corporibus marinis lapidescentibus quæ defossa reperiuntur. Romæ, 1670. I have seen only the editions of 1747 and 1752.

[92] B. Cerutus e Andreas Chioccus. Francisci Calceolarii Museum luculenter descriptum. Veronæ, 1622.

[93] Johann Daniel Major. Dissertatio epistolica de cancris et de serpentibus petrefactis, etc., Jena, 1664.

[94] Robert Hook. Micrographia, etc., London, 1665, p. 111.

(1665), Merret [95] (1667), Steno [96] (1669), Wedel [97] (1672), Boccone [98] (1674), Lister [99] (1678), Leibnitz [100] (1693), Tenzel [101] (1694), in the seventeenth; Carl [102] (1704), Rosinus [103] (1719), Kundmann [104] (1737), Schultze [105] (1755), Parsons [106] (1757), Blumenbach [107] (1780), in the eighteenth century, and numerous others, recognized in one form or another the real character of the fossils they were dealing with, some comparing them with living animals and plants, and some, especially in the later years, boldly combating the vagaries and supernatural explanations of the dominant schools. Most of these writers investigated the specimens themselves and drew their conclusions fresh from them, and in not a few cases the amount of such material in their hands for investigation was considerable.

During the seventeenth century these more rational utterances were of course without avail, but during the eighteenth they commenced to make themselves felt with increasing force. The diluvian hypothesis, as already remarked, was an advance toward the true conception, and the question now turned upon the manner in which these petrified remains of once living things could have been placed where they were found. Kundmann and Schulze were among the boldest, and Morand [108]

[95] Christopher Merret. Pinax rerum naturalium Britannicarum, continens vegetabilia, ammalia et fossilia in hac insula reperta inchoatus. London, 1666 & 1667.

[96] Nicolaus Steno. De solido intra solidum naturaliter contento dissertationis prodromus. Florentiæ, 1669.

[97] G. W. Wedel. De conchis saxatilibus. Ephemerid. Naturæ Curiosorum, 1672. III, pp. 101-103, Pl. LXX. Lipsiæ et Francf., 1681.

[98] Paul Boccone. Recherches et observations naturelles touchant le corail, etc., Amsterdam, 1674.

[99] Martin Lister. Historiæ animalium tres Angliæ tractatus quibus adjectus est quartus de lapidibus ad cochlearum quandam imaginem figuratis. London, 1678. See the "Præfatio" to this fourth treatise, in which, while favoring a *terrigenous* origin, he admits that if real animals they have now ceased to be generated. P. 199.

Idem. Synopsis methodica conchyliorum. 1685.

Idem. A description of stones figured like plants, and by some observing men esteemed to be plants petrified. Phil. Trans. London, 1673, Vol. VIII, No. 100, pp 6181-6191. Pl. I.

[100] G. W. Leibnitz. Acta erudita. Lipsiæ, 1693. P. 40.

[101] W. E. Tenzel. Epistola ad Magliabechum de sceleto elephantino Tonnæ nuper effossæ. Jena, 1694.

[102] Samuel Carl. Lapis Lydius philosophicus pyrotechnicus ad ossium fossilium docimasiam analytice demonstrandum adhibitus, etc. Franc. ad Mœnam, 1704.

[103] Michael Reinhold Rosinus. Tentaminis de lithozois ac lithophytis, olim marinis, jam vero subterraneis, prodromus, etc. Hamburg, 1719.

[104] J. C. Kundmann. Rariora naturæ et artis, oder Seltenheiten der Natur und Kunst des Kundmannscher Naturalienkabinets. Breslau u. Leipzig, 1737. I. Abschnitt, 14. Artickel.

[105] Ch. Fr. Schultze. Kurtze Betrachtung derer Kräuterabdrücke im Steinreiche. Dresden und Leipzig, 1755, S. 10.

[106] James Parsons. An account of some fossils, fruits, and other bodies found in the island of Shepey. Phil. Trans., 1757, Vol. 50, pt. 2, p. 396.

[107] Johann Friedrich Blumenbach. Handbuch der Naturgeschichte. Göttingen 1779-1780. 6. Aufl. 1799. Theil II, § 222, 225. (See especially pp. 688-708, ed. 1799.)

[108] J. F. C. Morand. Die Kunst auf Steinkohlen zu bauen. Leipzig u. Königsberg, 1771, 4°. (Translated from the French.)

(1771), Bauder [109] (1772), and Suckow [110] (1782), wrote treatises in the true scientific spirit. But to Blumenbach is generally ascribed the credit of having fairly broken the spell and prepared the way for a science of paleontology. Not only in his "Handbuch" already mentioned, but also throughout his later "Beiträge" [111] which began in 1790, and his other works, he taught with authority that the beings to whose former existence these fossil forms were due were not only antediluvian but preadamitic, and that moreover there had been a series of faunas and floras inhabiting the earth before the age of man.

The revolution, however, was not instantaneous nor abrupt. It had been preparing for many years and could not have been much longer postponed. To understand the nature of this preparation it will be necessary to consider a few of the questions that came up for discussion and solution during the eighteenth century, and in attempting to do this we must now confine ourselves exclusively to those presented by the different forms of fossil vegetation. Without denying the superior importance of the evidence from animal remains, it may still be possible to vindicate the truth of the rather paradoxical statement of Brongniart that the vegetable kingdom should perhaps claim the honor of having caused the ridiculous ideas which attributed these remains of the ancient world to freaks of nature and plastic forces to be abandoned. [112]

Among these questions the two that seemed to dwarf all others were, first, Are these the remains of the same kind of plants that are now found growing upon the earth? and, second, When did the originals live that have been preserved in this remarkable manner by turning into stone?

When we consider what is now known about the geological strata of the earth's crust we can scarcely realize that but two generations ago comparatively nothing was known on this subject. Geology was not yet born. The investigators of the last century were really not discussing the geologic age of fossil remains. The assumption was universal that these were plants that grew somewhere in the world only a few thousand years ago at most, plants such as either grew then in the countries where their remains were found or in other countries from which they had been brought by one agency or another, generally that of the Flood, or else, as some finally conceived, had been destroyed by these agencies, so as to have no exact living representatives. The writers of that period were therefore more or less divided among these three theories which we may respectively call (1) the indigenous theory,

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[109] F. Fr. Bauder. Nachrict von den seit einigen Jahren zu Altdorf von ihm entdeckten versteinerten Körpern. Jena, 1772.

[110] Georg Adolph Suckow. Beschreibung einiger merkwürdigen Abdrückevon der Art der sogenanten Calamiten. Hist. et comment. Acad. elector. Theodoro-Palatinæ, Tom. V, Physicum Monheimii, 1784, p. 355.

[111] Beiträge zur Naturgeschichte. 1790–1811.

[112] Histoire des végétaux fossiles, Tome I, p. 2.

(2) the exotic theory, and (3) the extermination theory. The most of them, however, admitted two or more of these explanations to account for different facts which could not be brought under a single one.

Scheuchzer, the great apostle of the Flood theory, considered the fossils as ordinary plants still to be found, and he gave them names taken from the standard botanical works, with all of which he was familiar, as well as with the flora of Switzerland, the Alps, and Europe in general. In the "editio novissima" of his "Herbarium diluvianum," 1723, he attempted in an appendix to arrange them all according to the system of Tournefort. Among the genera which he confidently puts down are found Gallium (= Galium), Fragaria, Fumaria, Osmunda, Saxifraga, Sorbus, Trifolium, Vitis, etc., and he occasionally ventures to give the species, as *Populus nigra*. Volkmann, in his "Silesia subterranea" (1720), is not less certain that he sees in one impression the myrrh of the Scriptures, and in another the common Hippuris, or mare's-tail. Lange[113] (1742) and Moering[114] (1748) were satisfied with the faintest resemblances to living plants, while Lehmann[115] (1756) labored hard to prove that the impressions of *Annularia sphenophylloides*, which occur at different depths in the coal mines near Ihlefeld, Hohenstein, were flowers of *Aster montanus* (*A. Amellus* or *A. Sibiricus*) caught in full bloom and petrified *in situ*. Many others[116] preceded Walch, who was himself unable to free himself from the popular conceptions. He compared his Lithophytes with indigenous plants, from which he also derived certain supposed fossil flowers.

The exotic theory, though equally untrue with the indigenous theory, marked a decided advance, since it was the outcome of careful study, and a supposed escape from some of the objections to the other mode of explanation. Very early in the century certain authors had been led by curiosity or some other motive to compare the finest of these impressions with specimens of living plants, then already well represented in European herbariums, from many distant countries. The earliest case of this kind on record is that of Leibnitz, who in 1706 furnished a note[117] on the occurrence of impressions of supposed Indian plants in Germany, a conclusion which he arrived at from a comparison of fossils with living species from India, and believed them to agree. Twelve years

[113] Nicolaus Langius. De schisto ejus indole atque genesi meditationes cum descriptione duorum vegetabilium rariorum, etc. Acta Acad. nat. cur., Tom. VI. App., p. 133, tab. II.

[114] Paul Gerard Moering. Phytolithus zeæ Linnæi in schisto nigro. Acta Acad. nat. cur., Tom. VIII, p. 448.

[115] J. G. Lehmann. Dissertation sur les fleurs de l'Aster montanus, ou pyrénaique précoce à fleurs bleues et à feuilles de saule, empreintes sur l'ardoise. Hist. de l'acad. des sci. et de belles lettres de Berlin, 1756, pp. 127–144.

[116] C. F. Schultze. Die bei Zwickau gefundenen Kräuterabdrücke. Neue gesellschaftl. Erzählungen, 1758. Theil I, pp. 42–48.

P. F. Davila. Catalogue systématique et raisonné des curiosités de la nature et de l'art. Paris, 1767. See Tome III, pp. 237–254, Pl. VI, VII, VIII.

[117] Histoire des sciences, Paris, 1706, pp. 9–11.

later Antoine de Jussieu[118] published his celebrated memoir upon the coal plants of Saint Chaumont, in which he discussed the differences between them and European ferns and their resemblance to those of the tropics.

The idea of the tropical facies of fossil plants was thenceforward frequently put forth, as by Lesser[119] (1735), Capeller[120] (1740), Sauvages[121] (1743), etc. Parsons[122] (1757) declared that some of the petrified fruits found on the Island of Sheppey were "absolutely exotics," and Dulac[123] (1765) discovered in the coal mines of Saint Etienne, now so carefully explored by Grand' Eury, impressions which he likened to American ferns. Walch leaned toward the exotic theory, and declared that so imperfect were the remains that their true identity could not be made out, and that the tendency had been too much to imagine indigenous species to exist where they were in reality foreign ones. He pointed out the fact that the fossil plants of England, France, and Germany were substantially the same, which is not the case to any such extent with the living floras, and even where no similarity with living plants could be traced he had no better explanation than that they must belong to unknown exotic species.

As intermediate between the exotic theory, or that of transportation by the Flood, and the extermination theory, or that of destruction by the Flood, and as, to some extent, an initial stage of the latter, there was called in a *degeneration* theory, which Volkmann[124] sets forth as clearly as it was probably ever conceived by any of the contemporary writers, which certainly is not saying a great deal. According to this theory the antediluvian vegetation was of a far higher order than that of postdiluvian origin, and contained none of the thorns, thistles, and other scourges with which we are familiar. It also contained many useful and wholesome fruit-bearing trees, of which our modern forests are the degenerate representatives. Ideas like these were frequently expressed, and even Buffon entertained some notion of a state of faunal and floral degeneration.

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[118] Examen des causes des impressions des plantes marquées sur certaines pierres des environs de Saint Chaumont. Mém. de l'acad. royale des sciences. Paris, 1718, p. 287. It is remarkable that both Brongniart (Hist. des vég. foss., Tome I, p. 3) and Schimper (Traité de pal. vég., Tome I, p. 4) should have committed the error of crediting this paper to Bernard instead of Antoine de Jussieu. The former would have been only nineteen years of age; but Brongniart makes the further mistake of assigning the date as 1708 (loc. cit., foot-note 1), which would have made him only nine years old. See also a second memoir, loc. cit., 1721.

[119] Friedrich Christ. Lesser. Lithotheologie, oder noturhistorische und geistliche Betrachtung der Steine. Hamburg, 1735, p. 642.

[120] Maurus Antonius Capeller. Sciagraphia lithologica. Gedani, 1740, p. 6.

[121] L'Abbé de Sauvages. Sur différentes pétrifications, etc. Mém. de l'acad. roy. des sciences. 1743, p. 415.

[122] James Parsons. Philosophical Transactions. 1757, Vol. L, p. 397.

[123] Alleon Dulac. Mémoire pour servir à l'histoire naturelle des provinces de Lyonnois, Forez, et Beaujolois. Lyon, 1765. Tome II.

[124] Silesia subterranea, p. 92.

The conception of a gradual degeneration would be logically followed with that of complete extinction, but, so far as we know, the latter view found expression earlier than the former. Leibnitz, in the memoir already cited (1706), speaks of the proofs of great physical changes taking place on the surface of the earth. Both Scheuchzer and Mylius admitted that many kinds of living creatures may have been utterly exterminated by the Flood. Jussieu proposed extinction as an alternative explanation. Rosinus[125] (1719) stated that among fossil Encrinites and Belemnites there were some whose originals were unknown. Volkmann and the other theological expounders believed in diluvian extermination, and thus explained the facts known to them that fossil trunks are often found on barren islands where no trees ever grew.[126] Walch admitted very little in this fertile direction, although he regarded the Calamitæ as the remains of great reeds which had no known living representatives. Suckow, however, in the memoir already referred to, where he was the first to recognize the affinity of the Calamitæ with Equisetum, decided, after careful comparison with *E. giganteum* and other large living species, that they probably belonged to extinct species.

The idea that the fossil remains might represent extinct species of forms once indigenous to Europe now began to take shape and to work a profound revolution in prevailing theories. The question then, referred to a few pages back, as to the time when the originals must have been living, became one of paramount importance and led to the investigation of the stratified rocks. This was the origin of true paleontological research. But it could scarcely have been begun earlier. Stratigraphical geology was also at the same moment in the act of being born. Werner had founded his Neptunian theory, and Hutton his Plutonian, while William Smith was teaching how to determine the age of rocks by the fossils they contain.

The puerile speculations about the nature of fossils which we have been considering can be better excused when we remember that nothing whatever was known of the earth. So long as it was supposed to be only a few thousand years old, and as the only disturbance of which men had ever heard was that of the Mosaic deluge, we may well doubt whether the most astute of our present geologists would have conceived any better explanations. In this respect the Ancients had the advantage. Even Pythagoras is said to have taught that the land was once under the sea. Xenophanes and Herodotus both expressed this same idea, and Aristotle himself is known to have entertained something like an adequate conception of time limits.[127] Tertullian (*supra*, p. 386, note 49) uttered the last faint echo of this thought, which thenceforward seems to have slumbered until the middle of

[125] *Supra*, p. 394, note 103.

[126] Volkmann. Silesia subterranea, p. 93.

[127] Meteorologicorum, Lib. I, Cap. XIV, 31; Lib. II.

the fifteenth century, when Leonardo da Vinci revived it, attacked the current scholastic doctrines, and maintained that the fossils which had been the subject of so much interest in Italy had been living creatures and had once lived in the sea. A century later Sarayna, as we have seen, asserted the organic origin of the Veronese petrifactions, and Fracastorius explained the fossils of the Kircherian, Moscardan, and Calceolarian Museums by assuming that the mountains containing them had stood in the water during the time the animals lived, and that these had left their remains on the retreat of the waters. These and all similar voices were, however, drowned amid the angry and senseless discussions of the time. Nicholas Steno, towards the end of the seventeenth century, in a work to which attention has already been called (*supra*, p. 394, note 96), recognized the different ages of stratified rocks, and asserted that the oldest rocks contained no fossils. In the posthumous "Protogæa"[128] of Leibnitz, which must have been written very early in the eighteenth century, a cosmogony is elaborated which recognizes something like the true process of sedimentation, but is vitiated entirely by an attempt to harmonize it with the literal six days cosmogony of Moses. Lehmann (1756), whose errors, so far as his conclusions were concerned, we have already mentioned, nevertheless performed a truly pioneer work both for geology and for paleobotany in correctly indicating the relative depth, position, and relations of the different strata with their characteristic vegetable remains in the coal region at Ihlefeld. These and a few other like treatises prepared the way for Blumenbach and the sound views which began to prevail at the close of the eighteenth century. The inadequacy of the Flood theory to explain the facts and the conviction that there must have been a series of antecedent revolutions in the floras and faunas of the globe began to inspire research, and promised the fruitful results which, in fact, so soon and so richly followed.

2. THE SCIENTIFIC PERIOD.

Having thus rapidly passed in review the long crepuscular period of speculation, conjecture, and groping research which was necessary to precede and prepare for the true advent of science—a period throughout most of which no real science of paleontology could be said to exist, or, if having a quasi-existence, its zoologic and phytologic branches were as yet for the most part undifferentiated—the scientific period, which, so far at least as plants are concerned, literally began with the beginning of the present century, next claims attention. In the biological sketches which preceded this historical one the chronologic arrangement was adopted, and in this, therefore, was necessarily embraced much of the true history of the science, but, as there stated, this form of treatment

[128] G. W. Leibnitz. Protogæa, sive de prima facie telluris et antiquissimæ historiæ vestigiis in ipsis naturæ monumentis dissertatio; ex schedis manuscriptis viri illustris in lucem edita a C. Scheidio. Gottingæ, 1749. § XLV treats of fossil trees and wood; § XLVI of peat, and § XLVII of the Luneburg fossil trees.

necessarily leaves out many of the important facts in the history of the subject. It also fails to connect the principal points into an unbroken series and to correlate events and discoveries into a systematic whole. The chiefly chronologic treatment which will now be presented, while still lacking in philosophic method and otherwise defective, will aim to supply most of the omissions referred to, and will perhaps be more useful than any other form of treatment which could well be made within the limited space which can be devoted to it.

The new epoch was auspiciously ushered in on the first year of the century by the memoir, already once referred to (*supra* p. 371), of the Baron von Schlotheim in Hoff's Magazine, in which he applied the same reasoning to plants that Blumenbach had done to animals.

Leopold von Buch[129] (1802) inaugurated the remarkable discussion as to whether the coal plants actually grew on the spot where they are found in the carbonized or silicified state, which was continued by Steffens,[130] Leonhard,[131] Noeggerath,[132] Sternberg, Brongniart, and Lindley and Hutton,[133] but is by no means settled, and still goes on in France, England, and the United States. Two papers, by M. Faujas de Saint Fond,[134] breathing the true scientific spirit of research appeared at about the same time and attracted much interest.

In 1804 appeared Von Schlotheim's epoch-making work, "Flora der Vorwelt," as it is now universally quoted, although the author himself merely entitled it a description of remarkable plant impressions and petrifactions, a contribution to the flora of the former (or primeval) world. To us this seems modest enough, but in view of the history of paleontology which we have been considering, we may readily see that this second part of the title was a bold declaration, and accordingly we find him defending it in his introduction by these words: "The petrifactions which so early engaged the attention of investigators, and which, without doubt, afforded one of the first incentives to the founding of mineral collections and to the earnest study of mineralogy and geology, have, as is well known, since Walch began to arrange them systematically, been for a long time, as well in as outside of Germany, almost wholly

[129] Leopold von Buch. Geognostische Beobachtungen auf Reisen durch Deutschland und Italien. Band I, Berlin, 1802. S. 92.

[130] Heinrich Steffens. Geognostisch-geologische Aufsätze. Hamburg, 1810. S. 267.

[131] K. C. Von Leonhard. Bedentung und Stand der Mineralogie. Frankfort, 1816. S. 70, 71.

[132] Jacob Noeggerath. Ueber aufrecht im Gebirgsgestein eingeschlossene fossile Baumstämme und andere Vegetabilien. Historisches und Beobachtung. Bonn, 1819–'21.

[133] Fossil Flora of Great Britain, Vol. II, pp. xvii, xx, xxii.

[134] Barthélemy Faujas de Saint Fond. Description des mines de Turffa des environs de Bruhl et de Liblar, connues sous la dénomination impropre de mines de terre d'ombre, ou terre brune de Cologne. Annales du Muséum d'histoire naturelle, Tome I, pp. 445–460, avec 2 planches. Paris, 1802. (See Pl. XXIX.)

Idem. Notice sur des plantes fossiles de diverses espèces qu' on trouve dans les couches fossiles d'un schiste marneux, recouvert par des laves, dans les environs de Rochesauve, département de l'Ardèche. (*Loc. cit.* Tome II, 1803, pp. 339–344, Pl. LVI et LVII.)

neglected. They were content to regard them as incontestable proofs of the Deluge, and closed all further investigation until they were at last compelled to explain their occurrence through other great natural operations which had probably been going on earlier and more universally than the flood described in the Bible, and influencing the formation of the upper strata of the earth's crust; and more recent observations and investigations have even led us to the very probable supposition that *they may be the remains of an earlier so-called pre-adamitic creation, the originals of which are now no longer to be found.* * * * In the continued investigation of this subject this opinion, with certain restrictions, has in fact gained a high degree of probability with the author of the present work, so that he ventures to announce his treatise as a contribution to the flora of the ancient world (*Vorwelt*)."

Since its introduction by Schlotheim this expression, "Flora der Vorwelt," has been applied to nearly all the German works on fossil plants, and "Beiträge zur Flora der Vorwelt" still continue to appear. Only one volume of this work appeared at this time, with fourteen plates; the completion, owing to political disturbances which so often interrupt the quiet march of science, was deferred until the year 1820, when the remaining plates were published with the first and with those relating to animal remains as an atlas to his "Petrefaktenkunde."[135]

Schlotheim worked conscientiously, drew his figures clearly and well, and sought diligently in all the European herbaria for forms with which his fossil plants could be compared. He seriously doubted the identity of the plant that had always been regarded as the common *Hippuris vulgaris*, and concludes that if any of the species he has figured are still living they must belong to tropical countries.

An important English work,[136] one volume of which is devoted to vegetable remains, and bears date 1804, or the same as Schlotheim's "Flora der Vorwelt," has for its title "Organic remains of a former world," the last two words of which are a fair translation of the German *Vorwelt*. Dr. Parkinson was a very learned man, and shows that he was familiar with the continental literature of his subject, but he nowhere refers to Schlotheim's work, and may safely be assumed to have been unacquainted with it.[137] The work is written in an erudite manner, and is full of historical interest, but as a contribution to science it is far inferior to that of Schlotheim. The figures, though better than most of those of the time, are less clear than the German author's, even where true leaf-prints and fronds are figured. But they mostly depict specimens of petrified wood and problematical fruits. Parkinson did

[135] See the "Petrefaktenkunde," p. 424.

[136] James Parkinson. Organic remains of a Former World. An examination of the mineralized remains of the vegetables and animals of the antediluvian world; generally termed extraneous fossils, Vol. I, containing the Vegetable Kingdom. London, 1804.

[137] A remark made by M. Schimper (Traité de pal. vég., Tome I, p. 8) might lead to the supposition that this work had been written many years later.

not regard it possible to identify the plants. For this work he called to his aid Dr. James Edward Smith, president of the Linnæan Society, an accomplished botanist, and together they faithfully compared all the specimens they had. The result was that while a greater or less similarity was detected between different ferns and the living genera Pteris, Dicksonia, Osmunda, Polypodium, and Adiantum, Dr. Smith was unwilling to say that they actually represented these genera, and he "conjectured that they were all foreign, and productions of a warm climate."

In the conclusions which he draws from the facts stated in the first volume of his work, Dr. Parkinson clearly shows that he is still heavily shackled by the current fallacies relating to the subject he has treated. The Deluge is still a potent influence and the "Former World" is not the modern geologist's *Paleozoic*, nor even the "Vorwelt" of Schlotheim.

Great activity in this branch of science followed the appearance of these works. As already shown (*supra*, p. 371), it was in 1804 that Count Sternberg began to write, though partly instigated by the papers of Faujas de Saint Fond,[138] who still continued his investigations.[139] Voigt[140] (1807) discussed the so-called Psarolithes of the Museum Lenzianum at Jena, and pronounced them fossil polyps, but retracted this decision the next year,[141] and admitted their vegetable character. Weppen[142] (1808) also mentions a number of specimens of petrified wood from the East Indies, Siberia, and various parts of Europe. This question was further treated by Steffens,[143] Oken in his "Lehrbuch der Naturgeschichte,"[144] Hoff,[145] and Schlotheim. Martin's "Petrificata Derbiensia"[146] is regarded as a forerunner of future work in Great Britain on the structure of trunks and on the study of the vegetable remains of the coal-measures. Schlotheim's "Beiträge zur Naturgeschichte der Versteinerungen in geognostischer Hinsicht"[147] (1813) was an appeal for greater thoroughness in paleontological research. In 1814 Kieser[148] first pointed out the characteristic structure of coniferous wood which

[138] Bemerkungen über die von Faujas de St. Fond beschriebenen fossilen Pflanzen. Botanische Zeitung. No. 4. 29. February, 1804, pp. 48–52.

[139] Faujas de Saint Fond. Memoirs in the "Annales du muséum d'histoire naturelle", Tome VIII, 1806, p. 220; Tome XI, 1808, p. 144; and in the "Mémoires," Tome II, 1815, p.444; Tome V, 1819, p. 162.

[140] Johann Karl Wilhelm Voigt. Kurze minerogische Bemerkungen. Leonhard's Taschenbuch für Mineralogie. Erster Jahrgang, pp. 120–124.

[141] *Idem. Loc cit.* Zweiter Jahrgang, pp. 385–386.

[142] J. A. Weppen. Nachricht von einigen besonders merkwürdigen Versteinerungen und Fossilien seines Kabinets. Leonhard's Taschenbuch, Band II, p. 178.

[143] Heinrich Steffens. Handbuch der Oryktognosie, Halle. 1811, Band I, p. 172–186.

[144] Th. I, p. 300, 1812.

[145] K. E. A. von Hoff. Beschreibung des Trummergebirgs und des ältern Flötzgebirgs, welche den Thüringen Wald umgeben. Leonh. Taschenb., Band VIII, 1814, p. 350.

[146] William Martin. Petrificata Derbiensia; or, Figures and descriptions of Petrifactions collected in Derbyshire. 4to, Wigan, 1809.

[147] Leonhard's Taschenbuch, Band VII, 1813, p. 1.

[148] Dietrich Georg Kieser. Elemente der Phytonomie, oder Grundzüge der Anatomie der Pflanzen. Jena, 1815. Appendix.

has had such an important bearing on the study of petrified woods. In 1796 Hagen[149] had published a memoir on the origin of amber, which was supplemented by Dr. John, of Cologne, in his large work[150] on that substance, discussing it from almost every conceivable point of view. Relative to the kind of tree that is supposed to have produced the amber he says (p. 168) it is very probable that a species of the genus *Pinus* formerly grew in Prussia which, as is the case with many other plants, is now wholly extinct.

Passing over some less important memoirs we come to that of the Rev. Henry Steinhauer "On Fossil Reliquia of Unknown Vegetables in the Coal Strata."[151] Few papers of this period are more often or approvingly quoted than this. Although presented to an American society by one of its members, then a resident of Bethlehem, Pa., it treats the subject in a thoroughly general way. The author had evidently spent the greater part of his life in Great Britain, and was well acquainted with British localities and British fossils. In fact, no mention whatever is made of any American locality, and the paper would have been perfectly at home in any of the scientific journals of England. The remark, therefore, of M. Schimper[152] to the effect that Steinhauer had laid the foundations of vegetable paleontology in America by a study of the vegetable impressions of the coal-measures of this country, seems not to be historically accurate. Probably the most important feature of this able paper is the attempt made in it to classify the vegetable remains of the Carboniferous. No special mention has thus far been made of similar previous attempts by Scheuchzer, Walch, Schlotheim, etc., because the more complete treatment of this important subject is reserved for a future place as an independent and connected study, and we will not anticipate this branch of our subject here.

Omitting a number of works in which vegetable fossils are either expressly treated, or least casually referred to, as by Ballenstedt and Krüger,[153] Raumer,[154] Schweigger,[155] d'Aubuisson de Voisins,[156] and Nilsson,[157]

[149] K. G. Hagen. De succini ortu. Ueber den Ursprung des Bernsteins. Riga, 1796; see, also, Gilbert's Annalen, Band XIX, 1805, p. 181.

[150] J. F. John. Naturgeschichte des Succins, oder des sogenannten Bernsteins. Köln, 1816.

[151] Transactions of the American Philosophical Society. Philadelphia, Vol. I, 1818, p. 265.

[152] Traité de Pal. Veg. Tome I, p. 16.

[153] J. G. F. Ballenstedt. Die Urwelt. 3. Aufl. Quedlinburg, 1819.

Johan Gottlob Krüger. Geschichte der Urwelt. Leipzig, 1820, Bd. II, pp. 95–254.

Ballenstedt & Krüger. Archiv für die Entdeckung in der Urwelt. 6 Bde. Quedlingburg, 1819–1824.

[154] Carl von Raumer. Das Gebirge Niederschlesiens . . . geognostisch dargestellt. Berlin, 1819, p. 166 (Anmerkungen).

[155] A. F. Schweigger. Beobachtungen auf naturhistorischen Reisen. Berlin, 1819.

[156] D'Aubuisson de Voisins. Traité de Géognosie. 1819, Tome II, pp. 294, 298.

[157] Sveno Nilsson. Om Försteningar och Aftryck af tropiska trädslag, Blad, ormbunkar och rörväxter m. m. samt trädkol, funna i ett Sandstenslager i Skåne. Kongl. Vetenskaps Akademiens Handlingar, 1820, pp. 108–122, 278–293.

which appeared in 1819 or 1820, the last named of which contains the earliest descriptions of the plant remains of the interesting locality of Hör, in South Sweden, afterward more carefully studied by Brongniart,[158] we find in the year 1820 three treatises of prime importance: Rhode's "Pflanzenkunde der Vorwelt,"[159] Schlotheim's "Petrefactenkunde," (*supra*, p. 371), and Sternberg's "Flora der Vorwelt" (*supra*, p. 371). Rhode studied the coal plants of Silesia, and was the predecessor of Göppert in that line of work. He discovered the now well-known fact that thick stems often silicify within while carbonizing without, which he discussed as well as the questions treated by Schlotheim and his predecessors relative to the real nature of plant impressions. He figured Lepidodendron, Sigillaria, and other coal plants, and his plates are still frequently quoted. Like Lehmann, he mistook certain verticillate forms for flowers, but represented them none the less faithfully. His work was never finished, being interrupted by the premature death of the author. Sternberg treated the subject of vegetable remains both from the geognostic and the botanical points of view, and his work was undoubtedly the most advanced contribution that had been made up to this date. We have already referred to it in a general way, and as its chief interest centers upon the system of classification which he proposed we must defer the more detailed account of it until this subject is reached. Less than an eighth of Schlotheim's "Petrefactenkunde" is devoted to plants, but it is systematically arranged, and the families, genera, and species are named according to the binomial method of Linnæus, giving the work a decidedly modern appearance. About the only other work referred to in it is his own "Flora der Vorwelt," the plates of which are reproduced, and others added. He had evidently not met with the paper of Steinhauer, and appeared not to be aware of the labors of Sternberg.

These works gave a new impetus to the science of fossil plants, and in the following year a number of papers appeared describing discoveries in special localities in Germany,[160] France,[161] England,[162] and America.[163] In this year also appeared Adolphe Brongniart's first and very important paper on the classification and naming of fossil plants,

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[158] Annales des Science Naturelles. Tome IV, p. 200. Pl. XI, XII. Paris, 1825.

[159] J. G. Rhode. Beiträge zur Pflanzenkunde derVorwelt. Breslau, 1820.

[160] B. S. von Nau. Pflanzenabdrücke und Versteinerungen aus dem Kohlenwerke von St. Ingbert im baierischen Rheinkreis verglichen mit lebenden Pflanzen aus wärmeren Zonen. Denkschr. der kängl. Akad. d. Wiss. zu München, Band VII, 1821, S. 283.

[161] Alexandre Brongniart. Notice sur des végétaux fossiles traversant les couches du terrain houiller. Annales des Mines, Tome VI, 1821, pp. 359–370.

[162] Thomas Allan. Description of a vegetable impression found in the quarry of Craigleith. Trans. Roy. Soc., Edinb., Vol. IX, 1823, p. 235.

Patrick Brewster. Description of a fossil tree found at Niteshill, etc. *Loc. cit.*, p. 103, Pl. IX.

[163] Ebenezer Granger. Notice of vegetable impressions on the rocks connected with the coal formation of Zanesville, Ohio. Am. Journ. Sci., 1st ser., Vol. III, 1821, p. 5.

which has been quoted already (*supra*, p. 372), and will receive special attention further on.

Four important works appeared in 1822, viz., (1) a memoir by Adolphe Brongniart, contained in the "Description géologique des environs de Paris," by Cuvier and Alex. Brongniart (also in Cuvier's "Recherches sur les ossements fossiles," Tome V, pp. 640–674, éd. 1835), describing the fossil plants of the Paris basin; (2) Mantell's Fossils of the South Downs, or Illustrations of the Geology of Sussex, in which the plant remains, though meager, are mostly dicotyledonous, or fruits of Conifers, etc. (see Plates VIII and IX and pp. 157 and 262); (3) Martius, "De plantis nonnullis antediluvanis ope specierum inter tropicos viventium illustrandis;"[164] and (4) Schlotheim's "Nachtrag zur Petrefactenkunde," which, though chiefly devoted to animal fossils, contains an interesting chapter on fossil seaweeds.

Brongniart took up the subject of fossil seaweeds, or fucoids, the following year,[165] but with the exception of two or three unimportant papers nothing else appeared in 1823, though research was none the less active.

Much the same could be said for the year 1824, although the contributions of Buckland,[166] Sir Henry Thomas de la Beche,[167] and Dr. Mantell[168] in England, Defrance[169] in France, and Nilsson[170] in Sweden added to the stock of knowledge in this department. Sternberg published an important memoir in *Flora*,[171] and Martius began his great work on the palms,[172] which has at least proved an aid to paleobotany, and to which Unger eventually supplied the fossil department.

The year 1825 was characterized in England by an important illustrated work by Edmund Tyrell Artis, entitled "Antediluvian Phytology," which, notwithstanding Brongniart's criticism,[173] and the fact that most of his species have been obliged to give way, must ever remain one of the classics of paleobotany, though rather as a work of art than of science. The author discusses in a very rational manner the progress of ideas relative to geology, but shows the proximity of his time to the age of pure discussion by admitting that he had undertaken to prepare himself to write the work because "convinced of the importance of this

[164] Denkschriften der königlich-baierischen batanischen Gesellschaft in Regensberg, Band II, 1822, p. 121, Pl. II-X.

[165] Mém. de la Soc. d'Hist. Nat., Paris, Tome I, pp. 301-321, Pl. xix-xxi.

[166] Trans. Geol. Soc. London, ser. ii, Vol. I, Part I, p. 210.

[167] *Loc. cit.*, Pt. II, pp. 45, 162, Pl. VII, Figs. 2, 3.

[168] *Loc. cit.*, Part II, p. 421.

[169] Jacques Louis Marin Defrance. Tableau des corps organisés fossiles, précédé des remarques sur les pétrifications. Paris, 1824. (See pp. 123, 124, 126.)

[170] Kongl. Vetenskaps-Academiens Handlingar, 1824, pp. 143–148, Pl. II. Stockholm, 1824.

[171] Bd. VII, p. 689.

[172] C. F. Martius. Genera et species palmarum quas in itinere per Brasiliam annis 1817–1820. . . collegit. Monachii, 1824–1849.

[173] Hist. des vég. foss., Tome I, p. 6.

study in affording the materials on which the geologist may found his theoretical speculations." The plates are certainly beautiful and also faithful, and they have been largely drawn upon by later authors. A second edition of the work appeared in 183..

Three important papers by Brongniart appeared during the same year in the "Annales des sciences naturelles" (Tome IV, pp. 23, 200, 417), one of which has just been referred to. Sir Alexander Crichton's memoir on the climate of the antediluvian world [174] attracted considerable attention and was copied into several of the scientific journals on the continent.

During 1826 few results were made known, and the only monograph of special note that appeared in 1827 was Jaeger's "Pflanzenversteinerungen," [175] which was a praiseworthy effort, and although the illustrations fall below the standard erected by Schlotheim and Artis, the geognostic treatment has been considered able, and the work is still quoted.

The year 1828 is without question the most eventful one in the history of paleobotany, since it saw the issue of Brongniart's "Prodrome," and the commencement of his "Histoire des Végétaux fossiles" (*supra*, p. 372), which, taken together as they belong, form the solid basis upon which the science has since been erected. We will first consider the "Prodrome," which merely forms an introduction to the other work, not as it is, but as it was, designed by its author to be. The "Histoire" stopped before the cryptogamic series had been finished, but in the "Prodrome" he takes us through the phenogamic series also as he understood it. Brongniart's fundamental conception was that fossil plants were not the less plants, and that so fast as they really became known they should be placed in their proper position in the vegetable series and made to form an integral part of the science of botany. In his classification, which will be given in another place, he therefore had due respect for the natural system as then understood, but he nevertheless felt that geognostic considerations must be taken into the account, and he saw, with almost prophetic accuracy, that in passing up through the geologic series higher and higher forms of vegetable life presented themselves. This seems simple enough to us of this age, and might seem trite to the reader did we not find, several years later, some of the ablest authorities both in botany and geology warmly contesting it, as we shall presently see. Although unable to understand the complete continuity in the series, as modern evolution requires, and although affected by the Cuvierian idea of successive destructions and re-creations, still he insisted that each successive creation was superior to the one it had replaced, and that there had thus been, as it were, a steady progress from the

[174] Alexander Crichton. On the Climate of the Antediluvian World, etc. Annals of Philosophy, Vol. IX, pp. 97, 207. (See especially pp. 99–102.)

[175] Georg Friedrich Jaeger. Ueber die Pflanzenversteinerungen welche in dem Bausandstein von Stuttgart vorkommen. Stuttgart, 1827. (There is an abstract in French in the Ann. Sci. Nat., Paris, Tome XV, 1828, p. 92.)

lowest to the highest forms of vegetation. He believed in the gradual reduction of temperature in the climate of the globe from the earliest times, and in the purification of the atmosphere from a former excess of carbonic acid, favorable only to the lower types which then prevailed. He divided the geologic series into four great periods, the first extending through the Carboniferous, the second embracing the grès bigarré, or Buntersandstein, only, the third seeming to include the rest of the Trias, the Jurassic, and the Cretaceous, and the fourth completing the series. The table which he gives on page 219 is calculated to show the development of the higher types of vegetation in successively higher strata, and may profitably be compared with the one having the same form, which will be found below (*infra*, pp. 440–441). Of this table he remarks that in the first period there exist hardly anything but Cryptogams, plants having a more simple structure than that of the following classes. In the second period the number of the two following classes becomes proportionately greater. During the third period it is the Gymnosperms which specially predominate. This class of plants may be considered *intermediate between the Cryptogams and the true Phenogams* (Dicotyledons), which preponderate during the fourth period. The words italicized in the liberal translation here made are scarcely less than a prophecy, and one whose fulfillment is only now being tardily granted by systematic botanists. In this tabular exhibit Brongniart enumerates 501 species of fossil plants known to him, 240 of which belonged to the first period (Paleozoic), 25 to the second, 72 to the third, and 164 to the fourth. He also states the number of living species at 50,350. A comparison of these figures with those of our own time, as given in the table below, will afford a sort of measure by which to judge of the nineteenth century as an era of scientific discovery.

Brongniart propounded a theory for the primordial distribution of land vegetation over the globe which is well worth a passing notice, and is not weakened by modern theories of post-glacial distribution, which might also be true. His theory, in brief, was that it began on small islands, the only land then existing; that these islands became gradually united and consolidated into continents upon which a different vegetation, more varied, and more like the present vegetation could exist, and he says that it was not until after the formation of the chalk (*i. e.*, the beginning of the Tertiary) that such a continental vegetation seemed to have appeared. He concludes from this that it was from this period that large areas of the earth's surface began to be laid bare, and that true continents commenced to be formed. He regarded it as remarkable that great changes in both the flora and the fauna of the globe should have taken place almost simultaneously; that the age of Cycads should correspond with that of reptiles and the age of Dicotyledons with that of mammals (p. 221). But unless fresh discoveries of this last-named class of animals shall be hereafter made in the middle Cretaceous we must regard this second coincidence as now disproved.

The great work of Brongniart, his "Histoire des Végétaux fossiles," proceeds with only a brief historical introduction to the systematic elaboration of the fossil plants in the order laid down in the "Prodrome." One entire volume was finished and a second begun without completing the Cryptogams. Seventy-two quarto pages are all that appear in the published editions of the second volume, which are devoted to a thorough discussion of the Lycopodiaceæ. The first volume is illustrated by 166 plates, and 29 accompany the second volume.

Besides these works by Brongniart, which bear date 1828, no less than five other memoirs from his pen relating to fossil plants appeared in that year.[176] A number of other contributions to vegetable paleontology swell the extraordinarily rich literature of the subject in 1828, only one of which can be noticed in this hasty sketch. This is Anton Sprengel's "Commentatio de Psarolithis, ligni fossilis genere," the best treatise on fossil woods that had thus far appeared. He reviews the history of the subject from a rational stand-point, gives a systematic classification, and describes six species of *Endogenites*, illustrating internal structure in one plate. The work is a small octavo pamphlet of 42 pages, published at Halle, in Latin; but for one so unpretentious it has commanded a high tribute of respect.

In 1829 Phillips published Part I of his "Geology of Yorkshire," so well known to both geologists and paleontologists. Like most English writers, he was behind the writers of France and Germany in appreciating the revolution in modes of explanation which the logic of facts had wrought, and we find him saying (p. 16) that "of many important facts which come under the consideration of geologists the 'Deluge' is, perhaps, the most remarkable; and it is established by such clear and positive arguments that if any one point of natural history may be considered as proved, the Deluge must be admitted to have happened, because it has left full evidence in plain and characteristic effects *upon the surface of the earth*." But he proceeds to qualify this statement by the admission that organic remains "were certainly deposited in the rocks *before* the Deluge."

He enumerates (pp. 147, 148, 189, 190) and figures (Pl. VII, VIII) a number of Jurassic fossil plants from what he calls the Upper Sandstone, Shale, and Coal, which have formed an interesting chapter in the history of the Mesozoic flora of the globe. Brongniart's method of arranging these vegetable remains is adopted.

Passing over the year 1830, which was characterized by considerable activity, as evinced by numerous minor papers of Brongniart, Witham, and others, we will pause to consider the most important work of this time, which began to appear in quarterly numbers in 1831, viz., "The Fossil Flora of Great Britain," under the happy joint editorship of Dr. John Lindley, the eminent botanist, and William Hutton, the equally

[176] Annales des sciences naturelles, Vol. XIII, p. 335, XIV, p. 127, XV, pp. 43, 225, 435.

renowned geologist. This work continued to appear until 1837, when it was suspended. The whole is now bound in three shapely octavo volumes, and forms an indispensable part of the library of every paleobotanist. From such an authorship was certainly to be expected a work of the highest authority and merit, and, indeed, such it really is. The illustrations are as fine as could be attained for the octavo size, and the text is both ample and accurate; but the greater part of the introductory remarks in Volume I, as well as much of the general discussion throughout the work, is characterized by a most astonishing and apparently willful ignorance of the true principles of paleophytology as they were set forth by Brongniart, Sternberg, and even Schlotheim. One of the most remarkable aberrations of the book is the pertinacity with which the authors contend for the existence of cactaceous and euphorbiaceous plants in the coal-measures. It is true that Parkinson[177] had seen a fancied resemblance between certain stems and those of large cacti, and several similar guesses had been made by early authors,[178] who supposed they must find the counterpart of every fossil in the living flora, but all these imaginings had been long since laid aside only to be revived by the leading botanist of Europe.

The theory of a former tropical climate in England and temperate Europe is assailed, the existence of tree ferns in the Carboniferous is denied, and the relation of Calamites to the Equisetaceæ doubted, while to the now somewhat waning doctrine of atmospheric changes "much more probability is attached." The true secret of this sweeping skepticism is, however, not far to seek. It is found in the more general denial which is finally made of the conclusion to which an admission of these rejected theories would naturally lead, and had actually led M. Brongniart and others. The authors say: "Of a still more questionable character is the theory of *progressive development*, as applied to the state of vegetation in successive ages * * * in the vegetable kingdom, it cannot be conceded that any satisfactory evidence has yet been produced upon the subject; on the contrary, the few data that exist, appear to prove exactly the contrary." All the denials and assertions contrary to Brongniart's teachings are made to support this view. The existence of Cactaceæ, Euphorbiaceæ, and other Dicotyledons in the Carboniferous would negative development; the existence of a former tropical climate was a strong argument for the nebular hypothesis as well as for geologic progress; tree-ferns would argue such a former tropical climate; if Calamites could be shown to be a Juncus (Vol. I, p. xxx), a higher type would be found in Paleozoic strata and another point gained. Still another good point was thought to be gained by proving what is now admitted, that Coniferous plants occur in the coal. All botanists proper then held, as many still hold, that the Gymnosperms were a

[177] Organic Remains, Vol. I, pp. 430, 439, Pl. V, Fig. 8, Pl. IX, Fig. 10.

[178] Volkmann. Silesia subterranea, p. 106; Walch, Naturgeschichte der Versteinerungen, Tab. Xa, Xb, Xc.

subclass of the Dicotyledons, co-ordinate with the dicotyledonous Angiosperms. But, curiously enough, Brongniart had forestalled this argument by making the Gymnosperms of lower type, intermediate between the Cryptogams and the angiospermous Phanerogams. By a special insight, characteristic of true scientific genius, he had used their lower geological position as a partial proof of their lower organization, *i. e.*, had postulated evolution as an aid to organic research—a method which is now becoming quite common, although unsafe except in the hands of a master.

Much stress is laid upon the fact "that no trace of any glumaceous plant has been met with, even in the latest Tertiary rocks," the authors thus freely employing the fallacy which they elsewhere warn others to avoid, that because a class of plants has not been found, therefore it did not exist in a given formation. But to cut off the possibility of a reply to the position they take they finally declare that, "supposing that Sigillarias and Stigmarias could really be shown to be cryptogamic plants, and that it could be absolutely demonstrated that neither Coniferæ nor any other dicotyledonous plants existed in the first geological age of land plants, still the theory of progressive development would be untenable, because it would be necessary to show that Monocotyledons are inferior in dignity, or, to use a more intelligible expression, are less perfectly formed than Dicotyledons. So far is this from being the case that if exact equality of the two classes were not admitted, it would be a question whether Monocotyledons are not the more highly organized of the two; whether palms are not of greater dignity than oaks, and Cerealia than nettles." Teleologic and anthropocentric reasoning like this pervades all the discussions in the work and largely vitiates the scientific deductions. The elaborate experiment of Dr. Lindley, described in the first dozen pages of the third volume, was obviously animated by the same spirit of uncompromising hostility to the development hypothesis that inspired the vagaries that characterize the introduction to the first volume. By showing that the higher types of plants when long immersed in water are earlier decomposed than ferns, conifers, and palms, he thought he had demonstrated that the reason why we find no Dicotyledons in the Carboniferous is simply because they had not resisted, and from their nature could not resist, the destructive agencies to be overcome in the process of petrifaction. One could wish that he might look down upon the four thousand species of fossil Dicotyledons now known, and realize how vain had been his experiment as well as all his former theorizing.

One work of special interest and value appeared in 1832, "Die Dendrolithen in Beziehung auf ihren inneren Bau," by C. Bernhard Cotta. This was a renewed attempt to classify systematically and describe scientifically the various kinds of fossil wood that had been discovered. Following in the footsteps of Sprengel, but provided with far more and better material, Cotta made a special study of the internal structure of

all the trunks and stems in his collection, establishing new genera and species based thereon, some of which are still accepted, as, *e. g.*, *Psaronius*. He reduces the forms in which all vegetable remains occur to three general classes, viz., (1) mere impressions without any remnant of the original cause; (2) petrifactions proper, in which the original substance is replaced with precision by the particles which were in the solution in which the plant was immersed; and (3) true vegetable remains whose substance is still present though somewhat metamorphosed, as, *e. g.*, lignite. This classification may be profitably compared with that of Schultze, in the work which has already been noticed.[179] His *Dendrolithen* embrace more than did Sprengel's *Psarolithi*, and aimed to include all the objects of this general class with which he was acquainted.

Witham's "Internal Structure of Fossil Vegetables" (*supra*, p. 373), appeared in 1833, and is the most exhaustive treatise thus far produced on the histology of paleobotany. He was evidently unacquainted with Cotta's "Dendrolithen," and, so far as the work itself would indicate, with Sprengel's "De Psarolithis." He confined his investigations entirely to British fossils, to which he is able in most cases to apply the systematic names given by Brongniart and Lindley and Hutton. The classification adopted is that of Brongniart. He makes his study comparative, and devotes two plates to the illustration of the structure of various kinds of wood of living trees.

One other important work appeared in 1833, viz., Zenker's "Beiträge zur Naturgeschichte der Urwelt,"[180] which, while describing animal remains from several localities and horizons, devotes 23 of its 67 pages, and three of the six plates to the description and illustration of the remarkable Cretaceous plant beds of Blankenburg in the Harz district. This memoir is remarkable for being the first attempt systematically to treat dicotyledonous fossils, and notwithstanding the adverse fate which has overtaken nearly all the names given at that and earlier periods to plants of all kinds, Zenker's genus, *Credneria*, still stands, and seems likely to stand much longer, if not perpetually. Though less well known than the Œningen leaf-prints, this locality was known to Scheuchzer, Brückmann, and Walch, but its systematic study as well as the initial step in the investigation of dicotyledonous fossil plants was reserved for Zenker in the second quarter of the nineteenth century.

The year 1834 would be sufficiently memorable in the annals of paleobotany if it had witnessed nothing more than the appearance of the first memoir[181] relating to the subject, from the pen of Doctor Heinrich

[179] Kurtze Betrachtung derer Kräuterabdrücke im Steinreiche, pp. 7–9.

[180] Jonathan Carl Zenker. Beiträge zur Naturgeschichte der Urwelt, etc. Jena, 1833.

[181] Ueber die Bestrebungen der Schlesier die Flora der Vorwelt zu erläutern. Schlesische Provincialblätter, August und September, 1834. Also in Karsten und Dechen's Archiv, Band VIII, 1835, pp. 232–249.

Robert Göppert, of Breslau, whose career we have already briefly sketched, and whose death since the first draft of that sketch was made occasioned an unavoidable shock notwithstanding the ripened age which our biographic notice showed him to have attained (*supra*, p. 373).

No important works on fossil plants appeared in 1835, and the principal production of 1836, in this line of research, was Göppert's "Systema Filicum Fossilium,"[182] which had probably been in preparation for many years. It was a masterly effort and fittingly betokened the great career of its author. The historical introduction remains the best review of paleobotanical science that has ever been written, and shows that the literature of the subject had long been a favorite pursuit of Dr. Göppert. Nearly all the figures of fossil ferns that had been drawn by the early authors were discussed and identified by the light of more recent knowledge. Rigid comparisons were instituted between fossil and living species, and systematic descriptions of the former so far as then known were introduced. In the forty-four plates that accompany the work are figured most of the Silesian species, which the author declares to be more numerous than those of any other country.

Göppert's contributions during the next year (1837) were numerous[183] and important, and, taken with the equally valuable ones of Brongniart,[184] render this year a good one for their branch of science.

The year 1838 was still more fruitful in published results, as many as a dozen memoirs having been produced in Europe. One of the most important of these has already been mentioned[185] (*supra*, p. 380), in which the first serious attempt was made to determine dicotyledonous genera by the aid of the nervation of their leaves.

In this year also appeared the eighth number of Sternberg's "Flora der Vorwelt," containing Corda's "Skizzen zur vergleichenden Phytotomie vor- und jetztweltlichen Pflanzen," whose merits have already been referred to (*supra*, p. 371).

The year 1839 produced the first contributions of both Geinitz (*supra*, p. 374) and Binney,[186] thus adding two important names to the roll of colaborers in this field. The Count of Münster's "Beiträge zur Petre-

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[182] Systema Filicum Fossilium: Die Fossilen Farnkräuter. Nov. Act. Acad. Caes. Leop. Car., Tom. XVII, Suppl., pp. 1-76.

[183] Uebersicht der bis jetzt bekannten fossilen Pflanzen. In Germar's Handbuch der Mineralogie, 1837.

Idem. Two papers on fossil wood: Neues Jahrbuch für Mineralogie, 1837, p. 403, and Verhandl. d. schles. Gesell., 1837, pp. 68-76; and an important one on the process of petrifaction: Poggendorf's Annalen, Band XLII, 1837, S. 593.

[184] Comptes Rendus, Paris, 1837, Tome V, p. 403; Proc. verb. de la soc. philom., 1837, p. 99; Mém. de l'Acad. Roy., Tome XVI, 1838, p. 397.

[185] Sul sistema vascolare delle foglie, considerato come carattere distintivo per la determinazione delle filliti. N. Ann. d. Sc. Nat. Bologna, 1838. Ann. I, Tom. I, pp. 343-390, Pl. VII-XIII.

[186] "On a microscopic vegetable skeleton found in peat, near Gainsborough." British Association Report, 1839 (Part II), pp. 71, 72.

factenkunde" also began to appear in that year, to which several of the most prominent German paleobotanists contributed.

Three very important works appeared in 1840. Bowerbank's "Fossil Fruits and Seeds of the London Clay"[187] marked a great advance in the state of knowledge of the remarkable bodies studied by him, and which, since Parsons[188] called attention to them in 1757, and in fact for many years previous to that time, had excited the interest of both the learned and the unlearned. Of these remarkable forms Bowerbank established ten genera, all but two of which (Hightea and Cucumites) are accepted by Schimper in his "Traité de paléontologie végétale." The number of species distinguished is quite large, and the descriptions and illustrations are very thorough and exact. The work is intensely scientific, and the reader is rarely referred to other authors or to any of the collateral circumstances that would have so greatly aided him in understanding it properly. Exact localities are rarely given, though the island of Sheppey seems to have furnished a large share of the specimens.

The work of Steininger,[189] treating of the fossil plants of what he designates as the "pfälzisch-saarbrückische Steinkohlengebirge," may next be mentioned, in which 83 species of coal plants are described, with 17 illustrations. The work, however, is chiefly geognostic.

Rossmässler's treatise on the lignitic sandstone about Altsattel in Bohemia,[190] almost marks an epoch in the science of fossil plants from the resolute, and in many respects, successful manner in which the author attacks the problem of dicotyledonous leaves, which had thus far been regarded as beyond the power of science to harmonize with the living flora. He clearly realized the objections to the use of Sternberg's universal genus *Phyllites* for all plants of this class, and in stating these objections he says, among other things, that in the great quantity of leaves that will be distinguished in the course of careful investigations of Tertiary strata the species of this vague genus *Phyllites* cannot fail to increase so enormously that all resources for deriving specific names will be exhausted. He first proposed to himself to determine the true genera to which the leaves seemed to belong, and then to append the old name *phyllites* to these genera, as, *e.g.*, Leuco-phyllites, Daphno-phyllites, etc.; but the fear of responsibility, the comparatively unimportant and local character of his work, and the advice of friends deterred him from car-

[187] James Scott Bowerbank. A History of the Fossil Fruits and Seeds of the London Clay. London, 1840.

[188] James Parsons. An Account of some Fossils and other Bodies found in the Island of Shepey. Phil. Trans., 1757, Vol. L, pp. 2, 396.

[189] J. Steininger. Geognostische Beschreibung des Landes zwischen der unteren Saar und dem Rheine. Ein Bericht an die Gesellschaft nützlicher Forschungen zu Trier. Trier, 1840.

[190] E. A. Rossmässler. Beiträge zur Versteinerungskunde. Erstes Heft. Die Versteinerungen des Braunkohlensandsteins, aus der Gegend von Altsattel in Böhmen. Dresden und Leipzig, 1840.

rying out his plan and decided him to employ under strong protest the old name. He described forty-eight Phyllites, all of which are so admirably figured as regards nervation that it has been no trouble for later writers to refer them to their proper genera. He also describes a palm (Flabellaria), several cones of Pinus, and a coniferous stem that he mistook for Stigmaria, though it is due to him to say that he recognized the entire novelty of finding a Stigmaria in the Tertiary formation.

In addition to these and some minor contributions during the year 1840, it was, as already shown, the one in which the earliest papers of both Unger[191] and Schimper[192] on fossil plants made their appearance.

The principal contribution made in 1841 was Göppert's "Gattungen der Fossilen Pflanzen,"[193] which appeared originally in six parts, with German and French text and many plates. It embraces a fundamental discussion of the existing knowledge of fossil plants. It must not be supposed that it is confined to the description of generic characters. The characteristic species of each genus are fully portrayed. The author still clings to the ancient floras, chiefly to the Carboniferous. The work has an unfinished appearance, and the parts have been put together by the publishers in a most slovenly manner, which, however, should not be allowed to detract from the true merits, as it certainly does from the usefulness, of this work.

A number of other papers by Göppert must be credited to 1841, the most important of which was his "Fossile Flora des Quadersandsteins von Schlesien,"[194] which he supposed to belong to the Tertiary system, while in connection with Beinert he published in the same year a memoir on the distribution of fossil plants in the Carboniferous formation.[195]

The little work of Alexander Petzholdt, "De Calamitis et Lithanthracibus" (Dresdæ et Lipsiæ, 1841), possesses merits not to be measured by its size. It has done much to clear up both subjects, and also to advance them, and the collection given of opinions which have been expressed by those best situated to know respecting the nature of the Calamitæ, and especially respecting the origin of coal, must continue to

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[191] *Supra*, p. 375, note 9.

[192] Baumfarne, Schachtelhalme, Cycadeen, Aethophyllum, Albertia * * * im bunten Sandstein der Vogesen; Hysterium auf einem Pappel-Blatte der Wetterauer Braunkohle. Lonhard und Bronn's Neue Jahrbücher, 1840, pp. 336–338. Communication dated 14. März, 1840.

[193] Die Gattungen der fossilen Pflanzen verglichen mit denen der Jetztwelt und durch Abbildungen erlautert (Les genres des plantes fossiles comparés avec ceux du monde moderne expliqués par des figures). Bonn, I–IV. Lfg., 1841, V–VI. Lfg., 1842–1845.

[194] Ueber die fossile Flora der Quadersandsteinformation in Schlesien als erster Beitrag zur Flora der Tertiärgebilde. Nov. Act. Acad. Cæs. Leop. Tom. XXIX, 1841, p. 97.

[195] Göppert & Beinert. Ueber Verbreitung der fossiler Gewächse in der Steinkohlenformation. Karsten & Dechen's Archiv., Band XV, 1841, p. 731.

have great historical value. As much may also be said for still another book of Petzholdt, published the same year, "De Balano et Calamosyringe (Additamente ad Palæologiam).

Although the first number of Unger's "Chloris Protogæa" appeared in 1841, still the work was not published until six years later, and contains preliminary matter of later origin and of such moment as to render it more proper to speak of the work as a whole in the chronological order of its final publication.

In 1842 numerous papers relating to fossil plants appeared in the current periodicals by Binney, Göppert, Gutbier, Kutorga, Unger, and others, all contributing to swell the literature of the science and supply the data for future generalization. Mr. Williamson's paper before the British Association of that year on the origin of coal (*supra*, p. 376) has already been referred to as a landmark to indicate the point of time at which he joined the growing band of workers in this field. Miquel's monograph of the Cycadaceæ,[196] although dealing chiefly in the living forms, takes account also of the fossil cycads, and forms a contribution to the subject that was much needed in its day. In Vanuxem's "Geology of New York," which forms Part III of the "Natural History of New York" (Albany, 1842), occur numerous figures of fossil plants, with some general remarks thereon.

Some dozen or more memoirs on fossil plants appeared in 1843, the most important of which were by Roemer[197] and Parlatore.[198] The first edition of Morris's "Catalogue of British Fossils"[199] (including fossil plants) also appeared in that year.

The number of contributions to the science of fossil plants in 1844 was considerably larger than in the previous year. It includes Schimper and Mougeot's "Monographie des plantes fossiles du grès bigarré de la Chaîne des Vosges," a work of considerable importance. In it are described and figured species of *Æthophyllum*, of surprising form and perfection, also *Yuccites* and other of the most ancient monocotyledonous types; Albertias, Voltzias, Schizoneuras, and Ferns.

Numerous short papers by Göppert relate to the lignite beds, and show that he was working up towards the subject of amber inclusions, which were soon to engross his attention; and one of these relates to the existence of amber in his own country,[200] and gives an historical ac-

[196] F. A. G. Miquel. Monographia Cycadearum. Trajecti ad Rheum. Fol. cum 8 tab.

[197] Friedrich Adolph Roemer. Die Versteinerung des Harzgebirges. Hanover, 1843, 4to.

[198] Filippo Parlatore. Intorno ai vegetali fossili di monte Bamboli e di monte Massi. Atti d. Georgofili d. Firenze, Vol. XXI, pp. 1–83. Firenze, 1843.

[199] John Morris. A Catalogue of British Fossils, comprising genera and species hitherto described with references to their geological distribution and to the localities in which they have been found. London, 1843. Second edition, considerably enlarged. London, 1854.

[200] Ueber das Vorkommen des Bernsteins in Schlesien. Uebersicht d. schles. Gesell., 1844, S. 228.

count of its discovery there, with a list of all the localities known to him. Besides giving a summary of the fossil flora of Silesia, in Wimmer's "Flora von Schlesien" (Breslau, 1844), Göppert prepared a laborious statistical paper[201] on the condition of the science at that date, which is highly interesting to consult now. The whole number of species then known to him was 1,778, of which 927 were vascular Cryptogams and 242 Gymnosperms.

Germar's great work on the Carboniferous flora of Wettin and Löbejün[202] began to appear in 1844 and continued in parts until 1853. Though treating of all the forms of life found in this district, the work is necessarily devoted mainly to plants, and the large folio plates display great thoroughness of treatment. To Dr. Audrä is due considerable of the text.

Probably no year since 1828 was more fruitful of results in paleobotany than 1845, and no year since has exceeded it, if we only speak relatively to the state of the science. Two of the greatest American contributors, Lesquereux[203] and Dawson (*supra*, p. 377, note 15), entered the ranks at this point, although their first papers gave little earnest of their future career. Besides some twenty minor papers and several small monographs and memoirs of permanent value, we have four large and important works that were either finished or well begun and fairly before the public on that year. Upon the first class we have here no space for comment. Among those of the second may first be mentioned Kurr's memoir on the Jurassic flora of Württemberg,[204] in which some dozen new species of Coniferæ, ferns, and lower Cryptogams are figured. His supposed discovery of true dicotyledonous (cupuliferous) wood has not been verified.

Two papers by Göppert are worthy of mention, one describing fossils from the coal measures of Siberia, collected by M. P. de Tchihatcheff, and published by that traveler in his "Voyage dans l'Altaï,"[205] with eleven plates, and one on the fossil flora of the middle Jura of Upper Silesia.[206]

[201] Ueber den gegenwärtigen Zustand der Kenntniss fossiler Pflanzen, 1844. Leonh. u. Bronn's Neues Jahrbuch, 1845, S. 405.

[202] Ernst Friedrich Germar. Die Versteinerungen des Steinkohlengebirges von Wettin u. Löbejün im Saalkreise. (Petrificata stratorum lithanthracum Wettini et Lobejuni in circulo Salsae reperta.) Halle, 1844–'53, fol. (Printed in German and Latin).

[203] "Quelques recherches sur les marais tourbeux en général." Mémoires de la Société des sciences naturelles de Neuchatel, Tome III, 1845.

[204] Johann Gottlob Kurr. Beiträge zur fossilen Flora der Juraformation Württembergs. Stuttgart, 1845 (Einladungsschrift zu der Feier des Geburtsfestes Sr. Majestät Wilhelm von Württemberg in der königl. polytechnischen Schule zu Stuttgart den 27. September, 1845).

[205] Description des végétaux fossiles recueillis par M. P. de Tchihatcheff en Sibérie, traduit du manuscrit allemand par P. de Tchihatcheff et publié dans son "Voyage scientifique dans l'Altaï Oriental et les parties adjacentes de la frontière de la Chine, pages 379 à 390, planches 25 à 35.

[206] Ueber die fossile Flora der mittleren Juraschichten in Oberschlesien. Uebersicht der schles. Gesellsch. 1845, p. 139.

Adolphe Brongniart named the fossil plants of Murchison's Geology of Russia[207] and published an explanatory letter.

One other paper of the minor class may be mentioned, chiefly because it describes American material, viz., that of Dr. James Hall in his report upon the vegetable remains collected by Frémont's expedition in 1842.[208] Eleven species of fossil plants are described in this report, besides the figure (Pl. II, Fig. 4), and mention of a dicotyledonous leaf, which last diagnosis is undoubtedly in so far correct. The determination of the ferns is also correct, except in the case of his *Glossopteris Phillipsii* (Pl. II, Figs. 5, *5a*, *5b*, *5c*), which is not a fern but another dicotyledonous plant, as may be seen by the secondary veins and the absence of the characteristic forked nervation of Glossopteris. In these and other respects these figures do not agree with those of Brongniart ("Hist. veg. foss"., Pl. 61, bis Fig. 5) and Phillips ("Geol. Yorkshire," Pt. I, Pl. VIII, Fig. 8). This is not the place to enter into the diagnosis and state the true affinities of these leaves, and indeed from the figures alone this would be a somewhat hazardous task; as yet only a few of the types figured are in my hands, and of this species only one of the least perfect specimens, but this and other unfigured fragments fully confirm its reference to the Dicotyledons. Of the geological position of the locality from which this material was derived one can perhaps speak with greater certainty. It is at least certain that it is not Oolitic, as Dr. Hall supposed, and it is probably Cretaceous, perhaps Laramie group. If the latitude and longitude (lat. 41½°, long. 111°) were accurately taken this would make Muddy Creek a tributary of the Bear River at a point which is colored as Cretaceous on the new map of the United States Geological Survey prepared by Mr. W. J. McGee (1884). The report will at least serve to direct attention to this locality.

Among the larger works that appeared in 1845, we will first mention Unger's "Synopsis Plantarum Fossilium," which is a carefully-prepared catalogue of all the fossil plants known to him with references to the works in which first described. The orders and genera are briefly characterized, and the localities are stated for the species. At the end is a summary, from which we learn that he had been able to enumerate 1,648 species. This, as will be remembered, is 130 species less than Göppert had enumerated a year earlier. It probably was, however, a closer approximation to the true state of the science. A complete index and a good bibliography rendered the work convenient for reference, and we can readily imagine its extreme usefulness at that date.

Probably the most important work of this year was Corda's "Flora

[207] Geologie de la Russie d'Europe et des montagnes de l'Oural, par Roderick Impey Murchison, Edouard de Verneuil, et le Comte Alexandre de Keyserling. Londres et Paris, 1845, Tome II, pp. 1-13.

[208] Report of the Exploring Expedition to the Rocky Mountains in the year 1842, and to Oregon and North California in the years 1843-'44. By Capt. J. C. Frémont, Washington, 1845, pp. 304-307, plates I and II.

der Vorwelt."[209] It is a large work in folio, with 128 pages of text and sixty magnificent plates, chiefly devoted to the illustration of the internal structure of petrified and carbonized trunks in various families of the vegetable kingdom and at different geological horizons, but mainly in the Carboniferous. As the only considerable work on this subject since Witham's (*supra*, p. 373), it was as much superior to that work as the aids to research were greater than they had been twelve years earlier.

In the same year also appeared Reuss's "Versteinerungen der böhmischen Kreideformation," to which Corda contributed the fossil plants in a chapter of sixteen quarto pages, with six plates executed with the same care and thoroughness that is characteristic of all his work.

One other masterly production, viz., Göppert's Amber-Flora, in Berendt's great work on amber,[210] will conclude the enumeration for the year 1845. His prolonged investigations into the lignite beds of Europe and his study of the amber found in Silesia naturally led to this broader undertaking and fittingly prepared him for it. He begins with a chapter on the amber tree. Of this he remarks that the pieces of wood that occur in and along with amber bear so close a resemblance to the specimens of lignite in his collection, that he does not for a moment hesitate, at least provisionally, to express the opinion that the amber of Prussia is probably derived from one species, which, from its similarity to the Coniferæ of the present epoch, he refers to the extinct genus Pinites, and which he designates as *Pinites succinifer*, and fully characterized in the systematic part of the work. This follows, beginning with a list of the species thus far found in amber, of which he enumerates fifty-three. He finds six other species of Pinites and twenty of Coniferæ. There are ten cellular plants (chiefly mosses and Hepaticæ), one fern, one gnetaceous species (Ephedrites), and twenty-one true Dicotyledons. The descriptions come next, and are accompanied by appropriate and very elaborate illustrations.

Very little idea of the true geologic age of these fossils is derivable from any of the statements contained in this work, either by Göppert or Berendt, and it is still quite the practice to refer these forms to the amber simply, without further attempt to fix their position. But in a paper read before the Silesian Society, May 11, 1853, Dr. Göppert expressed himself very clearly on this point. He said: "The manner in which this flora is composed, as well as the complete absence of one tropical or even subtropical form, points to the modern age of the amber formation, which we must unquestionably refer to the latest strata of the Tertiary formation, to the Pliocene division."[211] By this time the

[209] Beiträge zur Flora der Vorwelt, von August Joseph Corda, mit sechszig Tafeln Abbildungen. Prag., 1845.

[210] Georg Carl Berendt. Die im Bernstein befindlichen organischen Reste der Vorwelt. Erster Band, Berlin, 1845. I. Abtheilung: Der Bernstein und die in ihm befindlichen Pflanzenreste der Vorwelt (chiefly by Göppert).

[211] Jahresbericht d. Schles. Gesellschaft für vaterländische Cultur, 1853 (Breslau, 1854), pp. 46–62, (see p. 373).

amber flora had greatly increased, and 163 species are enumerated in this paper. This result was, however, in the main achieved through the indefatigable labors of Dr. Göppert.

In strong contrast with 1845 stands the next year, at least as regards the importance of the works produced relating to fossil plants. Dunker's monograph of the Wealden[212] is perhaps the leading contribution of 1846, and this embraces all departments of paleontology for that group. But the plants form a prominent feature. Fifty species of Wealden plants are enumerated as having been thus far found in Germany and England, nearly all of which are described and figured. In this last respect Dunker's work is all of a high order, which is nowhere more strongly displayed than in the treatise under consideration.

Göppert's papers were numerous in 1846, and at least one "Ueber die fossile Flora der Grauwacke oder des Uebergangsgebirges",[213] contained the germ of one of his future great works.[214]

Heer[215] and Bunbury (*supra*, p. 379, note 19) both commenced in 1846 to write on fossil plants.

The only great work devoted to paleobotany that appeared in 1847 was Unger's "Chloris Protogæa,"[216] which, as already stated, was published in ten numbers, the first of which came out in 1841. In the course of the preparation of these numbers his "Synopsis plantarum fossilium" appeared, which we have already noticed. The entire matter of this little work was introduced bodily, and apparently unchanged, into the larger one, forming its second part. The first part, or introduction, is entitled "Skizzen einer Geschichte der Vegetation der Erde." This is an able discussion of the leading problems as they presented themselves at that time and went far toward the solution of some of them. The body of the work is strictly descriptive, and here we find 120 species characterized, all new to science or consisting of corrected determinations of other authors. What specially distinguishes this work, however, from all that have thus far been reviewed is the very large percentage of dicotyledonous species, mostly from Parschlug, embraced in these descriptions. Considerably over one-half of the number belong to this subclass and to such genera as Ulmus, Alnus, Betula, Quercus, Acer, Rhus, Platanus, Ceanothus, Rhamnus, etc. He seems to have reached his determinations of these genera by an intuitive perception of the general and special resemblances of the fossil to the living leaves, with

[212] Wilhelm Dunker. Monographie der Norddeutschen Wealdenbildung. Ein Beitrag zur Geognosie und Naturgeschichte der Vorwelt. Braunschweig, 1846.

[213] Uebersicht der Arbeiten der schlesien Gesellschaft, 1846, pp. 178–184 (expanded in the Zeitschrift d. deutsch. geol. Gesellsch. Band III, 1851, S. 185).

[214] Fossile Flora des Uebergangsgebirges, Nov. Act. Acad. Caes. Leop. Car. Nat. Cur. Band XXII, Suppl. Breslau & Bonn, 1852.

[215] The first paper of which we have a record is the one "Ueber die von ihm an der hohen Rhone entdekten fossilen Pflanzen," which appeared in the Verhandlungen der schweizerischen Gesellschaft for 1846, pp. 35–38.

[216] Franz Unger. Chloris Protogæa. Beiträge zur Flora der Vorwelt. Leipzig, 1847.

which, as a thorough botanist, he was perfectly familiar. He nowhere refers to any treatise on the nervation of leaves, and as those of Bianconi (*supra*, p. 380, note 27) are not included in his "Literatura nostri ævi," it is probably safe to infer that he was unacquainted with them. In drawing his figures he adopted the old method of figuring the stone as well as all the defects in the impression, which while requiring an immense amount of unprofitable labor, rendered the result much less clear and less valuable than it would have been had these features been omitted. The fifty plates, however, by which this work is illustrated constitute an enduring monument to the skill, energy, and industry of their author.

Pomel's paper on the Jurassic flora of France,[217] which appeared in the official report of the association of German naturalists and physicians for 1847, though unaccompanied by illustrations, proved a highly important contribution and gave a new impetus to the study of that formation from the vegetable side.

Some dozen or more other memoirs of greater or less import were contributed during 1847 by Binney,[218] Fr. Braun,[219] Bunbury,[220] Göppert,[221] Lesquereux,[222] Rouillier,[223] and others, none of which can be specially considered here.

About thirty papers and books, small and great, relating to fossil plants appeared in 1848, none of which, however, can be ranked as great works, unless it be Bronn's Index Palæontologicus,[224] which merely includes the plants with all other fossils in one alphabetical arrangement. The number, however, of what may be classed as second-rate productions was quite large. Among these we may count Unger's "Flora von Parschlug,"[225] Berger's thesis "De fructibus et seminibus

[217] M. A. Pomel. Amtlicher Bericht der Versammlung der deutschen Naturforscher und Aertzte, 1847, pp. 332–354.

[218] Phil. Mag. Vol. XXXI, 1847, p. 259.

[219] Friedrich Braun. Die fossilen Gewächse aus den Gränzschichten zwischen dem Lias und Keuper des neu aufgefundenen Pflanzenlagers in dem Steinbruche von Veitlahm bei Culmbach. Flora, Regensburg, 1847, p. 81. (Enumerates 57 species of Rhetic plants.

[220] Quart. Journ. Geol. Soc. London, 1847, Vol. III, pp. 281, 423.

[221] Uebersicht der Arbeiten d. schles. Gesellschaft, 1847, pp. 70–73.

[222] Explorations dans le Nord de l'Europe pour l'étude des dépôts de combustibles minéraux. Bull. Soc. Sci. Nat. de Neuchâtel, Tome I, 1847, p. 471. *Idem* sur les plantes qui forment la houille. Bibl. Univ. Archives, Tome VI, p. 158. Genève, 1847.

[223] C. Rouillier. Etudes paléontologiques de Moscou, in Fischer de Waldheim's Jubilaeum semisecularem. Moscou, 1847. (Bois fossiles, pp. 20–24).

[224] Heinrich G. Bronn. Handbuch einer Geschichte der Natur. III. Band., III. Theil. Organisches Leben. Index Palæontologicus, oder Uebersicht der bis jetzt bekannten fossilen Organismen. Stuttgart, 1848-1849. A. Nomenclator palæontologicus, 1848. B. Enumerator palæontologicus, 1849.

[225] Die fossile Flora von Parschlug. Steiermärckische Zeitschrift, IX. Jahrg., I. Heft. 1848.

ex formatione lithanthracum,"[226] Binney "On the origin of coal,[227] three consecutive papers by Dr. J. D. Hooker in the Memoirs of the Geological Survey of Great Britain,[228] Debey, on the fossil plants of Aachen,[229] Göppert's prize essay on the formation of coal,[230] Raulin's "Flore de l'Europe pendant la période tertiaire,[231] Robert Brown's memoir on Triplosporites,[232] really announcing the discovery of the fruit of Lepidodendron, and Sauveur's "Végétaux fossiles de Belgique."[233] These works were all important additions to the literature of the science, and represented a large amount of original research.

The third volume of Bronn's Index Palæontologicus, namely, the *Enumerator*, did not appear until 1849. It contains Göppert's table of the vegetable fossils as known to him, arranged under their respective geological formations. All the species are enumerated in systematic order, but with an inconvenient appendix (pp. 5–72), and are not summed up at the end. The summary is, however, introduced in another part of the volume (p. 727), and shows that considerable progress had been made since 1847, when Unger made his synopsis in his "Chloris Protogaea," although, as already remarked, the 1,648 species there given is the same as given in his "Synopsis plantarum fossilium" (1845), which seems not to have been revised, while Göppert had already enumerated in 1844 (*supra*, p. 416) 1,778 species. From these figures we now have an advance to 2,055, or more than four times as many as were known to Brongniart in 1828, though only about one-fourth the number now known.

The great work of 1849 was Brongniart's "Tableau des genres de végétaux fossiles."[234] The author's views relating to the classification and

[226] Reinhold Berger. De fructibus et seminibus ex formatione lithanthracum. Dissertatio inauguralis quam consensu et auctoritate amplissimi philosophorum ordinis in alma litterarum universitate viadrina ad summas in philosophia honores rite capessendos die XVIII, M. Decembris, A. MDCCCXLVIII. H. L. Q. S. publice defendet Auctor. Vratislaviæ, 1848.

[227] Memoirs of the Literary and Philosophical Society of Manchester, Vol. VIII, 1848, p. 148.

[228] Vol. II, pp. 2—456.

[229] Verhandlungen des naturhistorischen vereines der preussishen Rheinlande, V. Jahrg., 1848, pp. 113, 126.

[230] Preisschrift. Abhandlung, eingesandt als Antwort auf die Preisfrage: * * * ob die Steinkohlenlager aus Pflanzen entstanden sind, etc. Eine mit dem doppelten Preise gekrönte Schrift. Haarlem, 1848, 4°, 300 S, 23 Taf., forming the 4e Deel, Tweede versameling, Verhandl. Holl. Maatschappen.

[231] Victor Raulin. Sur les transformations de la flore de l'Europe centrale pendant la période tertiaire. Annales des sciences naturelles de Paris, 3e série, Botanique, Tome X, 1848, p. 193.

[232] Annals and Magazine of Natural History, ser. II, Vol I, 1848, p. 376; Proc. Linn. Soc. I, 1849, p. 344; Trans. Linn. Soc., Vol. XX, Pt. I, 1851, p. 469, Pl. XXIII, XXIV. Cf. Comtes rendus des séances de l'Academie des sciences, Tome 67, 1868, pp. 421–426.

[233] J. Sauveur. Végétaux fossiles des terrains houillers de la Belgique, Académie royale des sciences, des lettres, et des beaux-arts de Belgique, Tome XXII, 1848.

[234] Tableau des genres de végétaux fossiles consideré sous le point de vue de leur classification botanique et de leur distribution géologique. Paris, 1849, 8°. Dictionnaire universel d'histoire naturelle.

distribution of the extinct genera and species of fossil plants are here systematically set forth and superbly illustrated. A memoir on the same subject[235] appeared in the "Annales des sciences naturelles" for the same year, in a manner summarizing his views and giving lists of fossil plants belonging to each horizon. In seeking to avoid all duplications that result from giving different names to different parts of the same plant, his enumeration is reduced to very modest proportions and falls inside of 1,600 species, while, by treating Œningen and Parschlug as Pliocene instead of Miocene, he greatly exaggerates the importance of the former horizon at the expense of the latter. But the era of Miocene exploration had only just begun, and that formation did not give evidence of its present overshadowing supremacy until the labors of Heer and Ettingshausen began to reveal its true character.

Pattison's "Chapters on Fossil Botany"[236] is a very superficial attempt to treat the subject in a popular way, and its only value is a table of British fossil plants, which, if it could be depended upon, would show the number then known to amount to 529, of which 279 were from the coal measures, 120 from the Tertiary, and 89 from the Oolite.

A large number of works and memoirs on vegetable paleontology appeared in 1850, perhaps exceeding that of any previous year. Most of these, however, were of modest pretensions, and only two can properly be classed among great works on the subject. These were Unger's "Genera et species plantarum fossilium"[237] and Göppert's "Monographie der fossilen Coniferen."[238]

As Unger had in 1845 published, in his "Synopsis," the first complete catalogue of fossil plants, so he was the first, in 1850, to publish a complete manual on the subject, for such is the nature of his "Genera et species." This work is a shapely octavo volume of 668 pages, written wholly in Latin, and describing in systematic order every species of fossil plant known to the author. The total number thus described is 2,421, a large advance upon any previous estimate. Among the good features of the work are an enumeration of the genera under their proper orders and classes in a table that precedes the descriptive part, the reproduction, brought down to date, of his previously published "Literatura nostri ævi," and a thorough species index at the end, distinguishing synonyms by printing them in italics. In his classification he follows the natural order of development, beginning with the lowest forms. He declines to follow the English authorities in

[235] Exposition chronologique des périodes de végétation et des flores diverses qui se sont succédé à la surface de la terre. Ann. Sci. Nat. Bot., 3e sér., Tome XI, 1849, pp. 285–338.

[236] S. R. Pattison. Chapters on Fossil Botany. London, 1849, 12mo.

[237] Franz Unger. Genera et species plantarum fossilium. Sumptibus Academiæ Cæsareæ scientiarum. Vindobonæ, 1850.

[238] H. R. Göppert. Monographie der fossilen Coniferen. Eine im Jahre 1849, mit der goldenen Medaille und einer Premie von 150 Gulden gekrönte Preisschrift. Leiden, 1850. Naturkundige Verhandelingen van de Hollandsche Maatschappij der Wetenschappen te Haarlem. Tweede Verzameling, 6e Deel. Leiden, 1850.

treating Stigmaria as a dicotyledonous plant. He places the "Cycadeaceæ" between the Cryptogams and the Monocotyledons, but strangely separates them from the Coniferæ and Gnetaceæ, which he makes to follow the palms and precede the forms now referred to the apetalous division; though he does not recognize by special names the divisions of the Dicotyledons established by Jussieu. Still, in arranging the orders, he follows the system of A. L. de Jussieu, and not that of Adrien de Jussieu. No illustrations accompany this work.

In Göppert's "Monographie der fossilen Coniferen" we have another of those exhaustive works upon difficult subjects which characterize this author. When we say that it forms a quarto volume of 359 pages, with 58 plates, half of which are devoted to the illustration of internal structure as revealed by microscopic examination, we have given but a rude idea of the work. The first 67 pages relate entirely to living Conifers and fitly prepare the way for a thorough treatment of the fossil forms. To the treatise on fossil Conifers is prefixed an historical introduction of nearly a hundred pages, in which, as in the historical introduction to his "Systema filicum fossilium," he marshals the literature with great effect, and, as in the former case he found it impossible to confine himself to fern life, so in the present case he makes it the occasion for a thorough study of the history of man's acquaintance not merely with coniferous fossil wood, but with fossil wood in general, which for ages remained the only known form of vegetable petrifaction.

Besides the systematic description of all coniferous fossils known to him, the work contains a most valuable enumeration of localities where fossil wood, beds of coal, and fossil plants in general had been found from the year 1821 to the end of 1849, arranged primarily according to their position in the geological system. It also contains an arrangement of the species of Coniferæ according to geological horizons.

The remainder of the numerous productions of the year 1850 must be passed over in silence, as their bare enumeration would consume considerable space, and without glancing at their special merits would add little to the reader's knowledge respecting them. As has already been stated (*supra*, p. 379, 380) it was in 1850 that both Massalongo and Baron von Ettingshausen began their work in the domain of fossil plants, so that at this date no less than fourteen of those who have been mentioned as leaders of the science were living and actively engaged in extending its boundaries.

We have thus passed in review the literature of fossil plants from the earliest records down to the close of the first half of the nineteenth century. The plan was, and still is, to continue this survey down to the present time, though confining attention more and more, as the literature increases in volume, to the most important works. But for the present purpose the carrying out of this plan is manifestly impossible from considerations of both space and of time, and it must be postponed until the work to which it was intended as an introduction

shall have been completed. This is specially to be regretted, as so little had been done down to 1850 to develop the paleobotanical resources of America. It is also true that at that date little had been done beyond the collection and accumulation of data for study. From the time when the practice of discussing imaginary problems without any data fell into disrepute the opposite and far more healthful tendency to treat facts as the end of research chiefly prevailed, until at length, at the time when we are compelled to close our record, a sufficiently large body of facts had been brought to light, and, through the organizing power of Unger, Brongniart, and Göppert, had been arranged for study and comparison, to render it somewhat profitable to speculate upon their probable meaning.

In the decade that followed some such speculation was indulged in very cautiously, but this always resulted in the clearer recognition of the need of still more facts, and undoubtedly tended strongly to stimulate research. Then commenced that systematic attack along the whole line of paleobotanical investigation. Ettingshausen's system of nervation for the determination of dicotyledonous leaves may be regarded as the result of the pressure, then irresistible, for the means of identifying the now vast accumulations of this important class of fossils. Heer's researches into the fossil floras of Switzerland and of the arctic regions, and Lesquereux and Newberry's investigations into the Dakota, Laramie, and Green River groups of the Western United States, together with Saporta's "Études" in the south of France, furnished more data than that of all the collections previously made from the later formations.

The work of exploration still goes on. Saporta has elaborated the Jurassic of France, Grand' Eury and Renault have thoroughly studied the Carboniferous of that country, as have Williamson and Carruthers that of England. Nathorst has opened up the subterranean floral treasures of Sweden, and Dawson those of British America, while Engelhardt, Hosius, Van der Marck, and Schenck have continued to investigate, without exhausting, the rich plant-beds of Germany. In America activity has not diminished, notwithstanding the advanced age of both the principal cultivators of this science. Large works, which have required years in preparation in the hands of both Lesquereux and Newberry, are either on the eve of publication or are far advanced toward completion. Professor Fontaine, of the University of Virginia, has an important work on the Rhetic flora of Virginia in press, and is collecting some most interesting material for a second from the lower Cretaceous or upper Jurassic of the same State. Large collections have lately been made by different parties of the United States Geological Survey, which are now in hand for examination, while fresh material is daily arriving at the National Museum from all parts of the country.

Between eight and nine thousand species (as species are made) of fossil plants are now known to science, and the time must be near at

hand, if it has not already come, when this wide acquaintance with the ancient floras of the globe, if properly organized for study, will afford such aid to geological investigation as to command recognition, while the lessons which it supplies to the botanist and the biologist will be inestimable.

VIII. NOMENCLATURE AND CLASSIFICATION OF FOSSIL PLANTS.

Science does not consist in names, but it cannot well progress without them, and early in the history of every science a system of nomenclature always arises. Again, a knowledge of natural objects consists largely in a knowledge of their relations, to obtain which systematic attempts at their methodical arrangement are among the first steps. However humble such efforts may at first be, they nevertheless constitute the beginnings of scientific classification. The objects may be arranged before names are given to them or to the groups they are seen to form, as in Bernard de Jussieu's Garden of the Trianon. But usually the naming either precedes or closely accompanies the process of arrangement. Such at least has been the case with fossil plants. This fact, however, is to be here considered: That the science of botany proper antedated by far that of paleobotany. A few names were given to vegetable remains during the period when nobody believed that they either were themselves plants or represented plants. The reaction from this view, which took place at the beginning of the eighteenth century, in favor of the diluvian theory, carried its votaries much too far, and led them to think that every fossil plant must represent some known living one. This extremism had its fitting exemplification in Scheuchzer's now obviously ridiculous attempt to classify the fossil plants of his time under the same rubrics as the living plants. The timely appearance of Tournefort's "Élémens de Botanique," in 1694, in which about the first real system of botanical classification was drawn up, afforded Scheuchzer the desired opportunity, and without waiting for the appearance of a second edition of his "Herbarium diluvianum," he hastened to arrange all his species under Tournefort's twenty-one classes, and published them, in 1816, in his "Oryctographia Helvetiæ" (pp. 203–247). In spite of his zeal, however, a large residue of unassigned fossil plants remained as a special "Class unkantlicher Gewächsen oder dero Theilen, welche uns von der Sündfluth ubriggeblieben" (p. 236). This attempt was continued in the *Editio novissima* of the "Herbarium diluvianum," published in 1723 (Appendix).

In this rash scheme Scheuchzer was not followed. Lhwyd, in 1699, had applied the term *Lithoxylon* to fossil wood, which, with the exception of the impressions described by Major, mentioned on p. 389 (*supra*), was the only form of vegetable fossil known down to his time.

Volkmann (1720) adopts this term, and also *Lithophyllon*, while to all impressions of leaves and fronds he gives the general name of *Lithophytes*, but he goes a long way in the direction of Scheuchzer in accepting the *indigenous* theory (*supra*, p. 395). Schultze (1755) treats the whole subject of plant impressions from a strictly mineralogical point of view, designating his figures by the old indigenous names of Scheuchzer and Volkmann; but the three general classes of petrifactions which he describes without naming are of interest, as showing that he possessed a firm and rational grasp of the phenomena. They are: (1) Whole trees, large trunks, thick roots, and other similar woody matters transformed into stone; (2) impressions of twigs, leaves, flowers, etc., which consist either in whole or in part of the remains of the originals in a petrified state; (3) impressions of stems, plants, and shrubs in which no trace of their former parts is perceptible.

Walch (1769) was the first to offer anything like a nomenclature of fossil plants, and although most of his names have now disappeared from the text-books, they still served a useful purpose during a long embryonic period in the history of the science. He called petrified trunks by the terms *Lithodendron* and *Dendrolithus*; pieces of petrified wood *Lithoxylon*, and also *Stelechites*; petrified roots, *Rhizolithus*. If the fossil remains bore a sufficient resemblance to any living tree or plant, it was called by the name of that plant, with its terminal syllable changed into *ites*, as *Daphnites*, *Sandalites*, etc., a method which is still extensively employed in the creation of fossil genera of plants. Herbaceous plants were called *Phytolithi*, but he distinguished mere impressions of these as *Phytotypolithi*. Fossil leaves were *Lithobiblia*, *Bibliolithi*, or *Lithophylla*. *Phytobiblia* referred to the leaves of herbs as opposed to those of trees. He mistook the *Calamitæ* for great reeds, and applied to them this name, as also that of *Lithocalmi*, the first of which has come down to us notwithstanding the misnomer. Fossil fruits he denominated *Carpolithi*, which is another term that has survived in the long struggle for existence.

Parkinson (1804) contented himself by giving a simple classification in English, although he refers to the Latin names which had been given to his groups by previous authors. His terminology was, (1) fossil trees; (2) fossil plants; (3) fossil roots; (4) fossil stalks; (5) fossil leaves; (6) fossil fruits and seed-vessels.

Steinhauer (1818) made four classes: Fossil wood (*Lithoxylon*), fossil fruits (*Lithocarpi*), fossil leaves (*Lithophylli* [*sic*]), and fossil flowers, of whose existence he seemed doubtful. He describes ten species, all of which he classes under the one genus, *Phytolithus*. Considering the meagerness of this presentation it is somewhat surprising that Steinhauer should have actually been the first to apply specific names to fossil plants, and thus to bring them fairly within the circle of natural history sciences. It had thus taken more than a century to complete the cycle from the attempt of Scheuchzer to apply Tournefort's classifica-

tion to fossil plants, through the "indigenous" and "exotic" stages incident to the diluvian theory and back to this humble beginning on a true scientific basis as a systematic science, and it is properly from the appearance of this unpretentious memoir in an American scientific serial that paleobotany as a systematic branch of natural history should date (*supra*, p. 403).

Baron von Schlotheim, in his "Flora der Vorwelt" (1804), had made no attempt to assign names to the forms he so admirably figured, but confines himself to questioning and criticising the "indigenous" and "exotic" names which they had received from the early authors. "If the author had established a nomenclature for the plants which he described," said Brongniart, "his work would have become the basis of all the works which have since been produced on the same subject."[239] But it was scarcely too late for him still to acquire this honor, for between this first work and the appearance of his "Petrefactenkunde" (1820) no important treatise on fossil plants other than Steinhauer's memoir was published, and in this second work, which, as we have already seen, so far, at least, as the treatment of vegetable remains was concerned, was merely the continuation of the first which had been interrupted by political troubles, a systematic nomenclature was adopted and carried out in detail (*supra*, p. 404). He styled the entire vegetable kingdom so far as fossils are concerned, Phytolithes, without, however, employing as Steinhauer had done, the term *Phytolithus* as a genus. Out of it he carves five classes, though he does not so denominate them. Under two of these larger divisions fall subordinate ones which may be called orders the other three remaining undivided with an ordinal and even generic rank of their own. The following is the outline of Schlotheim's system:

I. Dendrolithes.[240]
  A. Lithoxylithes.
  B. Lithanthracites.
  C. Bibliolithes.
II. Botanilithes.
III. Phytotypolithes.
  a.) Palmacites.
  b.) Casuarinites.
  c.) Calamites.
  d.) Filicites.
  e.) Lycopodiolithes.
  f.) Poacites.
IV. Carpolithes.
V. Anthotypolithes.

Under his Dendrolithes and Botanilithes no species are introduced, but certain forms are described, compared, and discussed. Especially

[239] Prodrome, p. 3.

[240] The anglicized forms are here employed as Schlotheim employed the German forms: *Dendrolithen*, *Lithoxylithen*, etc.

interesting are his notes on the Bibliolithes in which most of the dicotyledonous leaves, then known, are referred to. Of Palmacites he describes fifteen species under regular systematic names. Of Casuarinites he gives five species; of Calamites, ten; of Filicites, twenty-three; of Lycopodiolithes, five; of Poacites, four; of Carpolithes, fifteen, and of Anthotypolithes, one. The science of paleobotany could therefore start from this date with seventy-eight species described and figured.

Count Sternberg, in his "Flora der Vorwelt," established a large number of genera, which he founded upon the most thorough investigation, a large share of which have resisted the destructive agencies of subsequent research. Among these were *Lepidodendron*, *Flabellaria*, *Annularia*, *Nœggerathia*, and *Sphenopteris*. His determinations were modest and sound, and he was able only in a few cases to refer the fossil forms to living genera, as in *Osmunda*, *Asplenium*, etc. But the most important departure effected in this work was in establishing vegetable paleontology for the first time upon a geognostic basis. He assumed three periods of vegetation: (1) an insular period characterized by the great coal plants; (2) a period characterized by the predominance of cycadean types, and (3) a period introduced by fucoidal remains and characterized by dicotyledonous forms. It will be at once perceived that these three periods correspond substantially with the Paleozoic, Mesozoic, and Cenozoic ages of modern geology.

Passing over the system of Martius, published in 1822,[241] which, though having merits, has been received with less favor, we now come to that of Brongniart, the first draft of which also appeared in 1822.[242] In this memoir all fossil plants were divided into four classes, expressly so-called, viz., (1) stems whose internal organization is recognizable; (2) stems whose internal structure is not recognizable, but which are characterized by their external form; (3) stems joined to leaves or leaves only; (4) organs of fructification. The first class is divided into *Exogenites* and *Endogenites*, having the rank of genera. Under the second class, besides *Calamites* of Schlotheim, *Syringodendron* of Sternberg, and other genera, there occur for the first time the genera *Sigillaria* and *Stigmaria*. Sternberg's *Lepidodendron* is divided into *Sigillaria* and *Sagenaria*, to the latter of which Sternberg's name, *Lepidodendron*, is now generally preferred. Stigmaria is the equivalent of Sternberg's *Variolaria*. Under the third class *Lycopodites* is substituted for Schlotheim's *Lycopodiolithes*, *Asterophyllites* for his *Casuarinites*, and *Phyllites* for his *Bibliolithes*. Schlotheim's *Filicites* and *Poacites* are adhered to and the new genera, *Sphenophyllites* and *Ficoides*, are established. Under the fourth class Schlotheim's two genera, *Carpolithes* and *Antholithes*, are retained.

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[241] C. F. Martius. De plantis nonnullis antediluvianis ope specierum inter tropicos viventium illustrandis. Denkschr. der königl. baierisch. botan. Gesellsch. in Regensburg, Band II, 1822, pp. 121–147, Pl. I and II.

[242] Mémoires du Muséum d'histoire naturelle, Paris, Tome VIII, 1822, pp. 209–210.

Without further discussing here the beautifully illustrated work of Artis (*supra*, p. 406) who attempted, for the most part unsuccessfully, to create several new genera, we may now profitably compare the method just reviewed with the one put forth six years later by the same author in his "Prodrome." On page 9 of that work he gives the key to his new classification in the following words: "La méthode que nous avons adoptée pour classer et dénominer ces fossiles, est fondée également sur ces rapprochements plus ou moins intimes entre les plantes fossiles et les plantes vivantes." Laying aside the former method, based chiefly upon the nature of the fossil, *i. e.*, the part of the plant which happened to be preserved, he now makes bold to assign all these forms to some of the great natural divisions of the vegetable kingdom as established by the Jussieus and other botanists. But as already remarked (*supra*, p. 406), geognostic considerations and a firm faith in the laws of development led him to suggest some important modifications in this so-called natural method, as may be seen by comparing the following scheme from page 11 of the "Prodrome" and from page 20 of the "Histoire des végétaux fossiles":

I. Agams.
II. Cellular Cryptogams.
III. Vascular Cryptogams.
IV. Gymnospermous Phanerogams.
V. Monocotyledonous angiospermous Phanerogams.
VI. Dicotyledonous angiospermous Phanerogams.

In the present state of botanical science Brongniart's Agams would probably all be relegated to his second group, or Cellular Cryptogams, but in other respects this classification is pre-eminently sound, and seems likely to be vindicated by the future progress of the science as against some of the recent systems emanating from the highest authorities.

To these few general groups Brongniart proceeded to refer the fossil forms either as new and avowedly extinct genera, or, wherever possible, as extinct species of living genera. This was carried entirely through the system in his "Prodrome," and, so far as it went, the "Histoire" afforded ample justification for his determinations in the form of full descriptions and thorough illustrations. This latter work was in a manner completed by his "Tableau" [243] in 1849. The method of Brongniart has, with few exceptions, been adopted by subsequent paleobotanists, One of these exceptions, however, is too important to be passed over. although it has already been considered in certain of its bearings. This is the system of Lindley and Hutton. These authors, apparently in order to emphasize their dissent from the theory of development, reversed the order, placing the most highly developed forms first. They also placed the Coniferæ and Cycadeæ in the subclass Exogenæ, or

[243] Tableau des genres de végétaux fossiles considéré sous le point de vue de leur classification botanique et de leur distribution géologique. Paris, 1849. (Dictionnaire universel d'histoire naturelle.

Dicotyledons, without intimating that they differ in any essential respect from oaks or elms.

The following is their system in outline:

CLASS I.—VASCULARES, OR FLOWERING PLANTS.

Subclass 1. EXOGENÆ, OR DICOTYLEDONS.

Nymphæaceæ.
Laurineæ.
Leguminosæ.
Ulmaceæ.
Cupuliferæ.
Betulineæ.
Salicineæ.
Myriceæ.
Juglandeæ.
Euphorbiaceæ.
Acerineæ.
Coniferæ.
Cycadeæ.
Doubtful.

Subclass 2. ENDOGENÆ, OR MONOCOTYLEDONS.

Marantaceæ.
Asphodeleæ.
Smilaceæ.
Palmæ.
Fluviales.
Doubtful.

Flowering plants which cannot be with certainty referred to either the monocotyledonous or the dicotyledonous classes.

CLASS II.—CELLULARES, OR FLOWERLESS PLANTS.

Equisetaceæ.
Filices.
Lycopodiaceæ.
Musci.
Characeæ.
Algæ.

Plants the affinity of which is altogether uncertain.

Stigmaria is put in the Euphorbiaceæ, *Sphenophyllum* in the Coniferæ, *Annularia* and *Asterophyllites* in the Dicotyledons, *Nœggerathia* in the Palmæ, while *Sigillaria* and *Volkmannia* are classed with the last, or wholly uncertain group.

With the rapid increase of material for the study of fossil plants the possibility of referring them to living families and genera has increased

until at the present time nearly all the remains of the former vegetation of the globe are readily assigned to their proper place in the general system adopted by botanists. Within a few years the number of dicotyledonous species has become so large that the attempt to identify them has been eminently successful. By the aid of a set of rules deduced from the prolonged study of the nervation of leaves the genera of fossil Dicotyledons have been in great part made known. The only prominent question which this increased knowledge has raised in the department of classification has been with reference to the order in which the divisions of Jussieu should stand. It is, however, now generally admitted that the order in which these three divisions of plants appeared was that of Adrien de Jussieu and not that of A. L. de Jussieu,[244] the Gamopetalæ constituting the most recent group of plants developed upon the globe. M. Schimper, while adhering to the old method in this respect for his systematic arrangement of the families, has nevertheless clearly shown that this does not represent the order of nature, and in his review of these groups[245] he has arranged them according to the natural method.

It is thus that after two centuries of floundering in turbid waters the science of paleobotany has at last found itself in condition to take its proper place as a department of botany—the botany of the ancient world—in which, whatever geology may gain from it, it must rest upon geology as its solid foundation.

IX. THE NATURAL METHOD AS INDICATED BY PALEOBOTANY.

The aid that the study of fossil plants affords in arriving at a natural classification of living plants is of prime importance, because it supplies at first hand the chief object for which all classification legitimately exists, viz., a knowledge of how existing forms came into being and why they are what they are.

Much as we may delight in the discovery of new and beautiful forms, and may admire the objects in our possession as products of nature and pets of our specialties, we must, as investigators of nature, feel a higher interest in the great problems of their origin and development, whose solution in strictly scientific ways constitutes the proper aim of science itself.

The method by which these problems can be most successfully attacked is the method of *classification*. Notwithstanding the contempt into which mere "systematists" have latterly fallen, the true scientific method is still and must ever be the systematic method. The real cause for the present disdain of systematists, lies in the mistaken spirit in which

[244]Adrien de Jussieu. Cours élémentaire d'histoire naturelle. Botanique. Paris, 1840, p. 395.

[245]Traité de Pal. vég., Tome I, pp. 83–87

system-making has been so commonly conducted. Systems of classification had come to be regarded as the end of science, when they are at best only the means. But it is not to be wondered at that this was so, since it was not until quite recently that science could be fairly said to have any end other than to collect facts and build systems. Not until the laws of genetic dependence among the forms of organized life, as taught by Lamarck in 1809 and enforced by Darwin in 1859, had begun to be recognized within the last twenty years, was any such grand result thought possible as that of ever finding out how existing forms have come to be what they are. With the growth of this conception all attempts at classification gradually became revolutionized in their spirit and aim, and from being merely logical and ideal they tended to become practical and real. Whereas formerly some collected facts for the sake of facts, and others built systems for the sake of systems, now all collect facts for the sake of systematizing them and systematize them in order to learn what they teach; for neither without facts nor without system can we ever arrive at truth.

It is customary with botanists to speak of *artificial systems* of classification as contrasted with the *natural system*. It is commonly supposed that the system of Linnæus was wholly artifical, and the impression equally prevails that that of Jussieu was the true natural one. But in the progress of human discovery no such sudden leap ever takes place. The truth is that all systems have aimed to be natural and that none have wholly succeeded. But there has been progress in the conception of what constitutes a natural system. The most that the older botanists aimed to secure was a *logical* system, and it was supposed that the logical necessarily represented the natural.

1. TYPES OF VEGETATION.

The vegetation of the globe has always been divided into certain obvious groups which may be called *types*, the word "type" being here used in a very general and indefinite way. These types of vegetation have various systematic values. The following table contains the principal ones, with a brief explanation accompanying each:

Synoptical View of the Types.

CRYPTOGAMS.—Flowerless plants.
- *Cellular Cryptogams.*—Devoid of vessels or vascular bundles; *e. g.*, sea-weeds, mosses.
- *Vascular Cryptogams.*—Having vascular bundles—fibers, ducts, etc.
  - *Filices.*—Ferns.
  - *Rhizocarpeæ.*—Inconspicuous plants, of interest chiefly as appearing to form the transition from the Cryptogams to the Phænogams through the Cycadaceæ; *e. g.*, Marsilia, Salvinia, Azolla.

CRYPTOGAMS.—Flowerless plants—Continued.

Equisetineæ.—Rush-like plants, with whorls of leafless branches; *e. g.*, Calamites, scouring rushes.

Lycopodineæ.—Plants with scaly stems or trunks; *e. g.*, Lepidodendron, club-mosses.

Ligulatæ.—Inconspicuous plants, of interest chiefly as appearing to form the transition from the Cryptogams to the Phænogams through the Coniferæ; *e. g.*, Isoetes.

PHÆNOGAMS.—Flowering plants.

Gymnosperms.—Plants having their ovaries open and the ovules and seeds naked or exposed.

Cycadaceæ.—Trees midway in general aspect between tree-ferns and palms; *e. g.*, sago palm.

Coniferæ.—The pine family; *e. g.*, pine, fir, cedar, yew, etc.

Gnetaceæ.—A small family of leafless plants, interesting chiefly as appearing to form the transition from the Equisetineæ to the Dicotyledons, through the Casuarinæ; *e. g.*, Ephedra antisyphilitica.

ANGIOSPERMS.—Plants having their ovules and seeds protected by closed ovaries.

Monocotyledons.—Plants that come up with a single blade, or cotyledon; stems endogenous; *e. g.*, grass, lily, palm.

Dicotyledons.—Plants that come up with two leaves, or cotyledons; stems exogenous.

Apetalæ or *Monochlamydeæ.*—Plants having but one floral envelope (a calyx but no corolla); *e. g.*, oak, willow.

Polypetalæ.—Plants having two floral envelopes (a calyx and a corolla), the corolla consisting of separate petals; *e. g.*, rose, magnolia, maple.

Gamopetalæ or *Monopetalæ.*—Plants having two floral envelopes, the corolla consisting of a single piece, or petal; *e. g.*, honeysuckle, catalpa, trumpet-flower.

The names contained in this table are the modern ones, and other terms with, perhaps, about the same meaning will be found in the systems of classification of the older botanists, while in some such systems quite different groups are recognized as primary.

2. THE LINNÆAN SYSTEM.

The history of the progress made by botanists proper, without the aid of paleontology, in the direction of the natural method, did space permit, would well repay examination. I shall confine myself to presenting the three principal systems in a much-abridged form, as perhaps the most satisfactory way in which that progress can be indicated. The systems to which I refer are those, respectively, of Linnæus, of A. L. de Jussieu and of Adrien de Jussieu. The first of these, the system of Linnæus, is introduced merely to show that it is not altogether an arti-

ficial one, but, like all the rest, an effort at real classification. More clearly to indicate this I have arranged it in logical form, and, for brevity's sake, have introduced a number of non-Linnæan terms:

The Linnæan system.

Cryptogamia					Cryptogamia.
Phænogamia.	Diclinae				Polygamia.
					Diœcia.
					Monœcia.
	Hermaphroditæ	Gynandria			Gynandria.
		Eleutherogynia	Desmandria		Syngynesia.
					Polyadelphia.
					Diadelphia.
					Monadelphia.
			Eleutherandria.	Anisandria.	Tetradynamia.
					Didynamia.
				Isandria	Polyandria.
					Icosandria.
					Dodecandria.
					Decandria.
					Enneandria.
					Octandria.
					Heptandria.
					Hexandria.
					Pentandria.
					Tetrandria.
					Triandria.
					Diandria.
					Monandria.

All who are familiar with the Linnæan system will, of course, observe that the order is here inverted. The names of the successively larger groups, with the exception of the terms "Cryptogamia" and "Phænogamia," are merely invented to obviate the necessity of describing those groups. This form of presentation clearly shows to how large an extent Linnæus aimed at a logical classification.

3. SYSTEMS OF THE JUSSIEUS.

We will next glance at the systems of the Jussieus. Bernard de Jussieu has merely left us his catalogue of the garden of Trianon, but this enigmatic list of names is regarded by modern botanists as containing the germ of all later systems. Guided by it, his nephew, Antoine Laurent de Jussieu, proceeded to elaborate the celebrated Jussiæan system, of which a mere outline is presented in the following table:

System of A. L. de Jussieu.

Acotyledons.	
Monocotyledons.	
Dicotyledons	Apetalæ.
	Monopetalæ.
	Polypetalæ.
	Diclinæ.

This system, as will be observed, rests primarily upon the number of cotyledons, and in making the Cryptogams co-ordinate with the Monocotyledons and the Dicotyledons fails to draw the great dividing line which Linnæus clearly perceived between the Cryptogamic and the Phænogamic series.

In re-elaborating it, his son, Adrien, adhered to this defect, but introduced some improvements. We will next glance at this latest form of the Jussiæan system:

System of Adrien de Jussieu.

- Acotyledons.
- Monocotyledons.
- Dicotyledons ...
  - Diclinæ...........
    - Gymnosperms.
    - Angiosperms.
  - Hermaphroditæ ...
    - Apetalæ.
    - Polypetalæ.
    - Monopetalæ.

In this case we see a very great advance in the recognition of the Gymnosperms. In transposing the Polypetalæ and Monopetalæ he also departed from the views of his father, and in this modern botanists have not followed him, although, as remarked above (p. 431), this change would undoubtedly be in the direction of a true natural system.

4. SYSTEM OF MODERN BOTANISTS.

From the systems of the Jussieus to that which prevails among botanists of the present day the transition is slight. Linnæus's Cryptogamic and Phænogamic series are restored; the terms "Exogens" and "Endogens" are introduced as synonymous with "Dicotyledons" and "Monocotyledons," of which they take precedence; the Gymnosperms are recognized, and A. L. de Jussieu's order is restored for the Polypetalæ and Monopetalæ, for which latter name that of "Gamopetalæ" is coming to be preferred, while for "Apetalæ" the term Monochlamydeæ is substituted by some. The system, then, is substantially as follows:

- Cryptogams.
- Phænogams.
  - Endogens, or Monocotyledons.
  - Exogens, or Dicotyledons.
    - Gymnosperms.
      - Cycadaceæ.
      - Coniferæ.
      - Gnetaceæ.
    - Angiosperms.
      - Apetalæ, or Monochlamydeæ.
      - Monopetalæ, or Gamopetalæ.
      - Polypetalæ.

All modern text-books invert the order and begin with the Phænogams, but whether advisable or not this is intended merely to facilitate study, the higher forms being easier of comprehension, and does not at all imply that our leading botanists believe this to have been the order in which plants have developed. This inversion of the order, however, shows how completely the notion of development is ignored in modern botany, and the system throughout rests upon the evidence furnished by the organs of the plants as they are understood. It is proper to say that at the present time quite a large body of the most thorough students of vegetal embryology and histology, especially in Germany, have rejected much of this system, and especially that which concerns the Gymnosperms. These they prove in the most satisfactory

manner to constitute a lower type than any other of the Phænogams, and they conclude that they form a more or less natural transition from the Cryptogams to the Phænogams, between which they place them. This result is most gratifying to the paleontologist, for nearly or quite every work on fossil plants gives the Gymnosperms this position at the base of the Phænogamic series, so sagaciously assigned to it by Brongniart. Paleobotanists have been compelled to do this in the face of the prevailing botanical systems, because this is the position which they are found to occupy in the ascending strata of the earth's crust. It is astonishing that botanists could have remained so indifferent to such a weighty fact, and it is certainly most instructive to find the geological record, so long unheeded, confirmed at last by the facts revealed in living plants. There is no evidence that those who have thus confirmed it were in the least influenced by it, and Sachs is as silent as to paleontology as is Bentham or Gray.

The founders and perfectors of the prevailing system of botanical classification have not been influenced in any marked degree by the idea of development in vegetable life. Few of the earlier ones had ever heard of development, and those who had heard of it rejected it as a visionary theory. This system had become established long before the doctrine of the fixity of species had received a shock, for although Lamarck, himself a botanist, had sown the seed of its ultimate overthrow, still it required half a century for this seed to germinate, and it was during this half century that the Jussiæan system was supplanting the Linnæan and gaining a firm foothold.

It is our special task to examine this system by the light of the now universally accepted laws of development and to see in how far it conforms to those laws. We shall see that, with a few important exceptions and some unimportant ones, this purely logical classification is in substantial harmony with what we now believe to be the order demanded by the law of descent—an encouraging fact as showing that natural truth may often be correctly discerned by purely rational processes. Had Jussieu been told that the Monocotyledons and Dicotyledons were the direct descendants of the Acotyledons he would probably have treated the proposition with contempt. In his system the latter were placed before the former merely because they represented a lower grade of organization, and it was the relative grades of organization that determined the position of the minor as well as of the major groups throughout the Jussiæan system.

5. MODIFIED SYSTEM PROPOSED.

Now, therefore, that we have been compelled, from an entirely different class of evidence, to accept the fact of descent, we are glad to find that this does not wholly revolutionize the system arrived at from considerations of structure alone, while at the same time we must claim that this substantial agreement furnishes a strong corroboration of the theory of descent.

The following table may be taken to represent, so far as the tabular form will permit, the system of classification called for by the present known facts of structural botany and of paleontology.

Assumed natural system.

Cryptogams.			
Phænogams.	Gymnosperms.	Cycadaceæ.	
		Coniferæ.	
		Gnetaceæ.	
	Angiosperms..	Monocotyledons.	
		Dicotyledons.	Apetalæ.
			Polypetalæ.
			Gamopetalæ.

A glance at this table will show that the most important respect in which it differs from the one last examined is in the position and rank of the Gymnosperms. Whereas there the Gymnosperms and Angiosperms have only the rank of *subclasses* under the class Exogens, or Dicotyledons, they here assume the rank of *classes*, and the Monocotyledons and Dicotyledons are reduced to subclasses under the class Angiosperms. The Gymnosperms are thus taken out of the Dicotyledons entirely. This is done because the distinction of open and closed ovaries is regarded as a class distinction, and the Monocotyledons are as truly Angiosperms as are the Dicotyledons, since they possess the closed ovary; because the Gymnosperms are not dicotyledonous, the number of cotyledons varying from one to fifteen; and because, while all Gymnosperms are not strictly exogenous nor all Monocotyledons strictly endogenous, the woody structure of the Coniferæ differs fundamentally from that of all dicotyledonous plants. But a discussion of these points would carry us too far.

It will also be perceived that the order proposed by Adrien de Jussieu for the divisions of the Dicotyledons is here adopted, the reasons for which have already been referred to and will receive more special attention hereafter.

6. CLASSIFICATION OF THE CRYPTOGAMS.

Thus far we have considered the Cryptogams as an undivided group of plants; but they too are capable of subdivision. The classification of the Cryptogams, however, is still in its infantile stage and is the problem which is at this moment most earnestly claiming the attention of advanced botanists. The subject is too special to be entered into here, and I shall confine myself to naming a few of the groups which modern investigation has shown to throw some light upon the more general problem of descent in plant life.

That the first proper plants were cellular Cryptogams there is no question, and to that class still belong a great number and variety of forms, the seaweeds, fresh-water algæ, fungi, lichens, liverworts, mosses, etc. From these have in all probability descended the vascular Crypto-

gams, now chiefly represented by our ferns, club mosses, and scouring rushes. Leaving the cellular Cryptogams undivided, we will consider some of the groups of the vascular Cryptogams. The great preponderance of these forms of vegetal life throughout Paleozoic time renders this necessary, notwithstanding their insignificance at the present epoch.

As in the present, so throughout the past, the vascular Cryptogams are prominently divided into three great groups, which may be roughly designated as the fern group, the Calamite group, and the Lepidodendron group. Ancient ferns differed from those with which we are acquainted in being nearly all arborescent, or tree-ferns. The great Calamites of the coal-measures are now represented solely by our genus *Equisetum*, or scouring rush, while the *Lepidodendron* had degenerated into our little ground-pines and club-mosses (*Lycopodium*).

A careful study of the fossil remains of the Calamites and lepidodendroid growths of the Carboniferous period shows clearly that they were then much more closely related to each other than are the present Equisetaceæ and Lycopodiaceæ, and there can be little doubt that strictly intermediate forms existed. We may therefore class them together under a larger general group, to which we will give the name *Lepidophytes*. There is also a suggestive resemblance between some of the tree-ferns and certain of the Calamites, so that far back in that hoary antiquity of vegetable life we find a certain homogeneity and monotony, which show that those plant-forms as we now understand them were to a large extent undifferentiated and blended together.

Two small orders of cryptogamic vegetation, too rare to be frequent in a fossil state, and, indeed, unless formerly much more robust than now, too frail to admit of preservation except under the most favorable circumstances, possess for the modern cryptogamic systematist an extraordinary interest. These are the Rhizocarpeæ, or pepperworts, now chiefly represented by *Salvinia*, *Marsilia*, and *Azolla*, and the Ligulatæ, to which belong only *Isoetes*, the quillworts, and *Selaginella*. The reason for this special interest lies in the fact that the plants of these two orders, alone of all Cryptogams, possess characters which seem to mark the transition from the cryptogamic mode of reproduction to that of the Gymnosperms. In this the Rhizocarpeæ are supposed to approach more closely to the Cycadaceæ, while the Ligulatæ simulate rather the Coniferæ. On account of this exceptional prominence of these two orders I give them a separate place in the following table of classification of the Cryptogams:

Cellular Cryptogams.		
Vascular Cryptogams.	Filicineæ......	Filices (Ferns).
		Rhizocarpeæ.
	Lepidophytæ..	Equisetineæ.
		Lycopodineæ.
		Ligulatæ.

By uniting this table with the one last examined a somewhat com-

plete view of the classification warranted by the present knowledge of plant life may be gained.

7. GEOGNOSTICO—BOTANICAL VIEW OF THE PLANT LIFE OF THE GLOBE.

We will now attempt to marshal in as convenient a form as possible the principal facts which paleontology and modern botany afford, with a view to examining their bearings upon the problem of classification in general and upon those of descent and development in particular. In doing this we are compelled to depend upon the weight of evidence furnished by the *number of species* alone, since it is impossible to take account of the relative predominance of species, however great and important the differences may be in this respect. The number of species really marks the degree of variety or multiplicity, which certainly forms a rude index to the degree of abundance or prominence. Where a number of types are compared this difference in their degree of variety may fairly be assumed to apply to all alike, and the conclusions thus drawn will be measurably accurate; and in general this multiplicity of varying forms under larger types may be taken in a manner to represent the relative exuberance or luxuriance of the type, and thus roughly to indicate its relative predominance as a form of vegetation.

In all attempts to argue from paleontology allowance must, of course, be made for the imperfection of the geological record, and in no department is this imperfection greater than in that of plants. Yet it is certainly remarkable how large a portion of the earth's surface has, at one epoch or another, presented the conditions which have proved favorable to the preservation of vegetable remains. Our surprise at this is heightened when we contemplate the present state of the globe upon which that condition seems scarcely to exist. We know that the great land areas of our continents are wholly incapable of preserving the leaves that annually fall upon them, and it is only in the quiet beds of rivers that have reached their base level, or in their deltas, or else in localities where tufa-laden spring water flows over vegetation, or lastly, in our great swamps, that such a result is possible. This last condition is believed to furnish the key to the solution of the problem of most of the ancient vegetable deposits, but the limits of this paper forbid me to enter into a discussion of this subject.

The following table presents in a rough manner the history of the introduction of plant life upon the globe as revealed by the remains that have actually been discovered. It has been compiled from about 25,000 species slips which have been the product of nearly two years' labor in cataloguing the literature of Paleobotany. Although this work is by no means completed, still, it embraces nearly all the more recent and more important works on the subject, and hence cannot fall far short of affording a correct view of the present state of knowledge of the fossil flora of the globe.

Number of species of each of the principal types of vegetation that have been found fossil in
sible to ascertain; together with the percentage that

		Geological formations.	CRYPTOGAMS.											
			Cellular.		VASCULAR.									
					Ferns.		Rhizocarpeæ.		Equisetineæ.		Lycopodineæ.		Ligulateæ.	
			Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.
		Present time	35,000	23.89	3,000	2.05	100	0.07	30	0.02	500	0.34	400	0.27
Cenozoic.		Quaternary	27	33.3	4	4.9	.....	.....	2	2.5	.....	.....	.....	.....
	Tertiary.	Amber	37	55.2	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
		Pliocene	.....	.....	3	3.1	.....	.....	.....	.....	.....	.....	.....	.....
		Miocene	168	5.5	87	2.9	6	0.2	18	0.6	.....	.....	2	0.06
		Oligocene	17	2.2	17	2.2	1	0.1	3	0.4	.....	.....	.....	.....
		Green River	5	2.2	8	3.5	2	0.9	3	1.3	1	0.4	1	0.4
		Eocene	71	10.3	22	3.2	.....	.....	1	0.2	.....	.....	.....	.....
		Paleocene	3	2.5	7	5.9	.....	.....	.....	.....	.....	.....	.....	.....
Mesozoic.	Cretaceous.	Laramie	13	3.9	23	6.9	1	0.3	4	1.3	1	0.3	3	0.9
		Senonian	23	6.5	73	20.6	.....	.....	1	0.3	.....	.....	.....	.....
		Turonian	1	20.0	1	20.0	.....	.....	.....	.....	.....	.....	.....	.....
		Cenomanian	8	3.3	38	15.5	1	0.4	1	0.4	.....	.....	1	0.4
		Dakota	1	0.5	7	3.3	.....	.....	.....	.....	.....	.....	.....	.....
		Gault	.....	.....	10	27.8	.....	.....	.....	.....	.....	.....	.....	.....
		Urgonian	.....	.....	50	46.3	1	0.9	3	2.8	1	0.9	.....	.....
		Neocomian	10	25.6	12	30.8	.....	.....	.....	.....	.....	.....	.....	.....
	Jurassic.	Wealden	7	5.8	44	36.4	.....	.....	.....	.....	.....	.....	.....	.....
		Coral	19	29.2	12	18.4	.....	.....	.....		.....	.....	.....	.....
		Oolite	39	9.3	133	31.7	1	0.3	14	3.3	3	0.7	.....	.....
		Lias	13	9.7	44	32.8	.....	.....	4	3.0	.....	.....	.....	.....
		Rhetic	8	6.3	69	54.3	.....	.....	5	3.9	.....	.....	.....	.....
	Trias.	Keuper	.....	.....	15	36.6	.....	.....	3	7.3	.....	.....	.....	.....
		Muschelkalk	2	33.3	1	16.7	.....	.....	.....	.....	.....	.....	.....	.....
		Bunter Sandstein	.....	.....	7	31.9	.....	.....	1	4.5	.....	.....	.....	.....
Paleozoic.		Permian	6	1.8	186	55.4	.....	.....	26	7.7	9	2.7	.....	.....
		Carboniferous	17	1.2	627	42.4	.....	.....	143	9.7	368	24.9	.....	.....
		Subcarboniferous	5	3.7	64	47.4	1	0.8	20	14.8	25	18.5	.....	.....
		Devonian	33	17.6	79	42.0	3	1.6	16	8.5	28	14.9	.....	.....
		Upper Silurian	8	61.5	2	15.4	.....	.....	1	7.7	1	7.7	.....	.....
		Lower Silurian	40	90.9	1	2.3	.....	.....	1	2.3	2	4.5	.....	.....
		Cambrian	2	100.0	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....

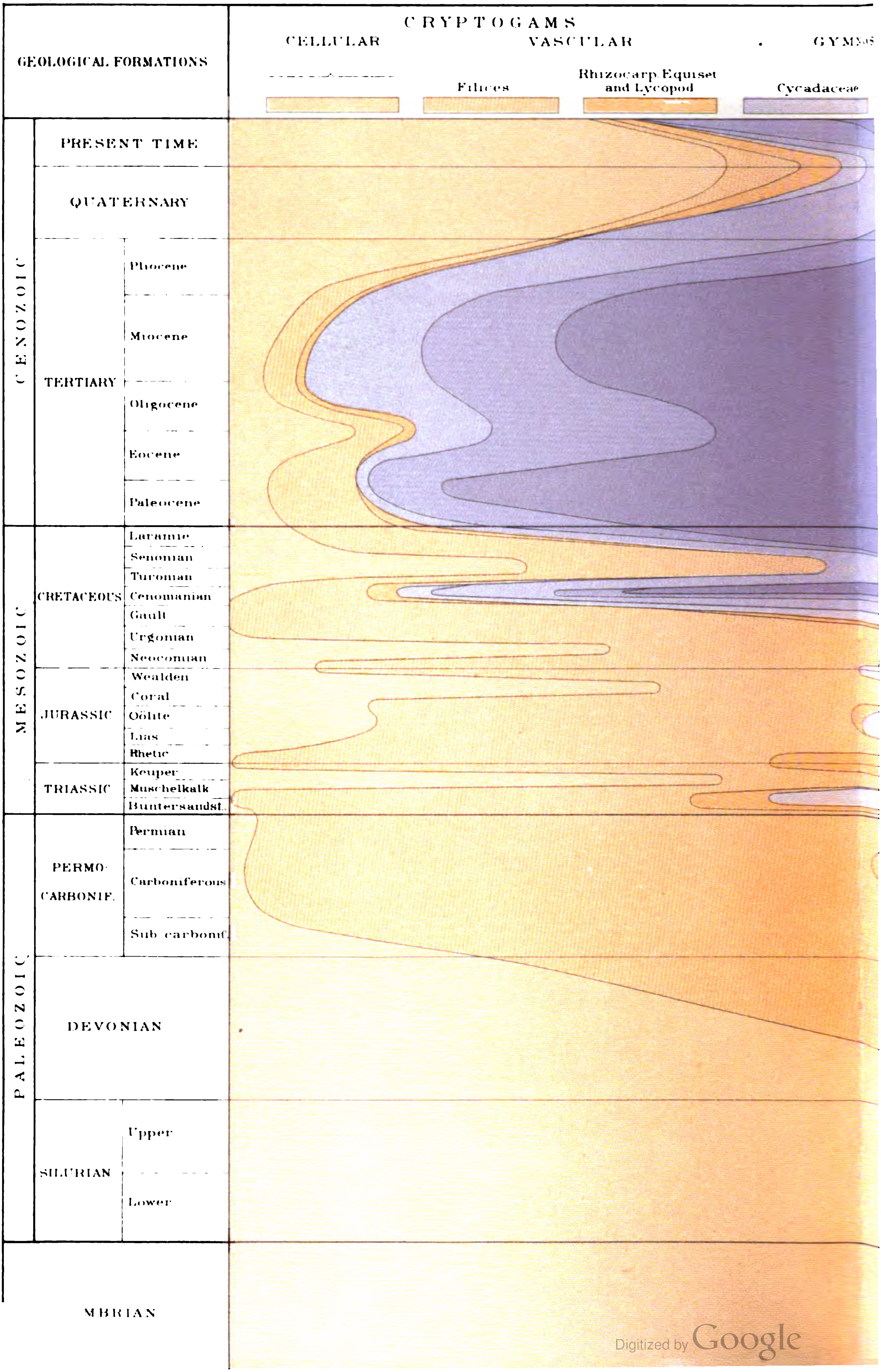
each geological formation, also the number existing at the present time as nearly as it is pos-
each type forms of the total flora of each formation.

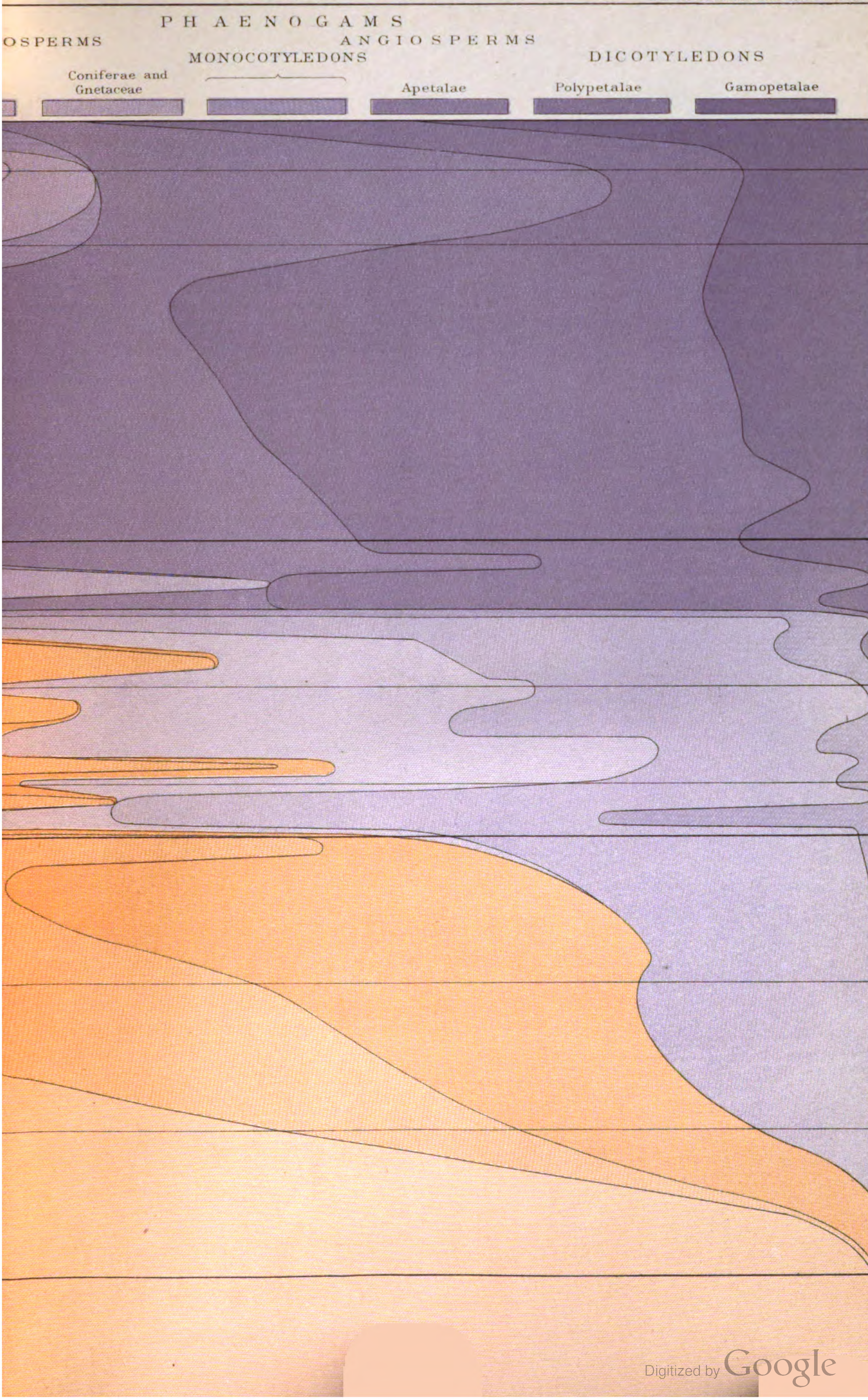
PHÆNOGAMS.																
GYMNOSPERMS.						ANGIOSPERMS.										Total.
Cycadaceæ.		Coniferæ.		Gnetaceæ.		Monocotyledons.		Dicotyledons.								
								Apetalæ.		Polypetalæ.		Gamopetalæ.				
Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.	Per cent.	Number.		
75	0.05	300	0.24	40	0.03	20,000	13.65	12,000	8.19	35,000	23.89	40,000	27.31	146,445		
2	2.5	4	4.9	......	......	......	......	27	33.3	8	9.9	7	8.7	81		
......	......	14	20.9	1	1.5	2	3.0	5	7.5	1	1.5	7	10.4	67		
......	......	13	13.3	......	......	9	9.2	32	32.6	31	31.6	10	10.2	98		
6	0.2	250	8.2	1	0.04	272	8.9	826	27.1	1,064	35.0	346	11.3	3,046		
2	0.3	64	8.3	1	0.1	82	10.6	256	33.1	259	33.6	70	9.1	772		
......	......	10	4.4	......	......	21	9.2	85	37.1	73	31.9	20	8.7	229		
3	0.4	34	4.9	......	......	116	16.8	162	23.5	221	32.1	59	8.6	689		
......	......	1	0.8	......	......	7	5.9	57	47.9	39	32.8	5	4.2	119		
1	0.3	15	4.5	......	......	33	9.9	125	37.5	84	25.2	30	9.0	333		
5	1.4	34	9.6	......	......	18	5.1	118	33.3	64	18.1	18	5.1	354		
......	...	1	20.0	......	......	......	......	......	....	2	40.0	......	...	5		
11	4.5	28	11.4	......	......	6	2.5	61	25.0	82	33.7	7	2.9	244		
7	3.3	12	5.6	......	......	5	2.4	88	41.3	84	39.4	9	4.2	213		
2	5.5	22	61.2	......	......	2	5.5	......	....	......	......	......	......	36		
21	19.4	25	23.2	......	......	6	5.6	1	0.9	......	......	......	......	108		
6	15.4	9	23.1	......	......	2	5.1	......	......	......	......	......	......	39		
43	35.5	26	21.5	......	......	1	0.8	......	......	......	......	......	......	121		
17	26.2	17	26.2	......	......	......	......	......	......	......	......	......	......	65		
116	27.7	103	24.6	1	0.3	9	2.1	......	......	......	......	......	......	419		
58	43.3	10	7.5	......	......	5	3.7	......	......	......	......	......	......	134		
26	20.5	18	14.2	......	......	1	0.8	......	......	......	......	......	......	127		
15	36.6	7	17.1	......	......	1	2.4	......	......	......	......	......	......	41		
......	......	3	50.0	......	......	......	...	......	......	......	......	......	......	6		
3	13.6	7	31.8	......	......	4	18.2	......	......	......	......	......	......	22		
14	4.1	92	27.4	......	......	3	0.9	......	......	......	......	......	......	336		
8	0.5	307	20.8	......	......	8	0.5	......	......	......	......	......	......	1,478		
......	......	20	14.8	......	......	......	......	......	......	......	......	......	......	135		
......	......	29	15.4	......	......	......	......	......	......	......	......	......	......	188		
......	......	1	7.7	......	......	......	....	......	......	......	......	......	......	13		
......	......	......	......	......	......	......	....	......	......	......	......	......	......	44		
......	......	......	......	......	......	......	....	......	......	......	......	......	......	2		

Before entering upon a general survey of the development of plant life as shown in this merely numerical exhibit, it will be necessary to refer the reader to three diagrams (plates LVI, LVII, LVIII), which have been prepared with a view to rendering the principal facts embraced in the table more readily intelligible, and then to discuss each of the diagrams separately, keeping the numerical data constantly in view. For the execution of these diagrams I am indebted to Ensign Everett Hayden, United States Navy, on duty at the National Museum in the Department of Fossil Plants, who has not only plotted and drawn them, but has aided me greatly in selecting from among the many possible modes of graphic illustration the ones which, as I believe, most successfully serve this purpose.

In all the diagrams an effort is made, of course in an approximate and very rude manner, to indicate time-measures in terms of thickness of strata, this being, however imperfect, certainly the only standard attainable. In a lecture delivered at the National Museum on February 24, 1883, on *Plant Life of the Globe, past and present*, enlarged diagrams having a similar object to those introduced here were used for illustration. The data then obtainable for their preparation were very defective, and the time-measures were taken from Dana's "Manual of Geology." Those who may remember them, from notes taken or otherwise, will observe that in this latter respect the accompanying diagrams differ widely from the ones presented on that occasion. Upon investigation it appears that the views of geologists generally have changed materially since the appearance of the last edition of that work, and recent observations have tended to show that the thickness formerly assigned to Mesozoic, and especially to Tertiary, strata was much too small in proportion to that assigned to Paleozoic, and especially to Silurian strata. After consultation upon this subject with the Hon. J. W. Powell, Director of the Survey, it was decided that nearly equal vertical space might be given to each of the following formations, or groups: 1, Cambrian; 2, Silurian; 3, Devonian; 4, Permo-Carboniferous; 5, Jura-Trias; 6, Cretaceous; 7, Eocene; 8, Mio-Pliocene. These have accordingly been taken as furnishing the scale of time equivalents, and all the diagrams have been drawn to this scale.

The development of vegetable life through geologic time may be discussed from three somewhat distinct points of view. We may, in the first place, consider each of the principal types of vegetation at each of the geologic periods in which it occurs solely with reference to its relative importance in the combined flora of that epoch. This is undoubtedly the most important point of view from which the subject can be contemplated, and has accordingly been considered first. It is clear that the data for this must consist, not in the actual number of species at each horizon, but in the proportion, or percentage, which this number forms of the total number found at such horizon. Diagram No. I is, therefore, based upon these percentages as given in the foregoing table.


GEOLOGICAL FORMATIONS
CRYPTOGAMS
CELLULAR
VASCULAR
GYMNOS
Filices
Rhizocarp. Equiset and Lycopod
Cycadaceae
PRESENT TIME
QUATERNARY
CENOZOIC
TERTIARY
Pliocene
Miocene
Oligocene
Eocene
Paleocene
MESOZOIC
CRETACEOUS
Laramie
Senonian
Turonian
Cenomanian
Gault
Urgonian
Neocomian
JURASSIC
Wealden
Coral
Oölite
Lias
Rhetic
TRIASSIC
Keuper
Muschelkalk
Buntersandst.
PALEOZOIC
PERMO-CARBONIF.
Permian
Carboniferous
Sub carbonif.
DEVONIAN
SILURIAN
Upper
Lower
MBRIAN


PHAENOGAMS
OSPERMS
ANGIOSPERMS
MONOCOTYLEDONS
DICOTYLEDONS
Coniferae and Gnetaceae
Apetalae
Polypetalae
Gamopetalae

In the second place, we can consider each type of vegetation by and in itself, with a view to determining the geological age in which it first made its appearance, the general nature of its progress through time, and the period of its maximum actual development as an element of the vegetation. Such a presentation, however, when based on the number of species actually found at each horizon, exhibits very great fluctuations, due to the irregularities in the record. These irregularities depend chiefly upon conditions quite independent of the real presence or abundance of the plants in any formation. These conditions are many, but the principal ones may be embraced under three heads: 1. The plants must have existed at the period in question. This is the legitimate assumption and alone gives value to the diagram. 2. The conditions for their preservation and then for their subsequent exposure must have occurred. Any one can see how exceedingly irregular must be these delicate conditions at different ages of the world. 3. The localities in which they are embedded must have been discovered and worked by the paleontologist. This is the great contingency which stands in the way of our acquaintance with any flora, but although doubtless more potent than the one last named, it possesses the merit of possible removal through the industry of man.

With all these detractions from its value this form of illustrating the geological record is nevertheless presented in Diagram No. II.

In the third place, we may, by a legitimate exercise of the rational method of science, construct a scheme of illustration, based indeed upon these facts as indispensable landmarks, yet recognizing the law of uniformity in natural processes that constitutes the primary postulate of science itself, which shall, to a large extent, eliminate the error of the defective record and present a rational and highly probable view of the true development. By a second act of ratiocination the probable period of first appearance of each type of vegetation may be deduced from the fact as to the earliest point at which it has actually been discovered, and thus an approach far nearer, at least, to the true history of plants than is possible by the last-named method may be made. Diagram No. III presents the subject from this third point of view.

Discussion of Diagram No. I.—In this diagram the Cryptogams are represented in buff tints and the Phanerogams in purple, with deeper shades for the successively higher types of each series. The diagram is based upon the assumption of the proportionate representation of types in the known floras of each age. Collectors of fossil plants never select. They take everything they find and make no attempt to find particular forms. If, therefore, the chances of preservation of different kinds of plants were equal the chances of finding any particular kind would depend upon its actual degree of abundance in the given flora. Conversely, the degree to which any type of plants is represented in the collections made would be a fair measure of such abundance or of the relative prominence of the type in the flora of the given epoch. How-

ever imperfectly such a flora was represented in the collections, this relation would theoretically hold, and thus the imperfection of the geological record would be eliminated so long as it was only contemplated from this relative stand-point. And although it is not true that all kinds of plants stand an equal chance of preservation, still the classification of plants according to their adaptability to preservation is wholly different from their systematic botanical classification and traverses the latter in such a manner as rarely to coincide with its boundary lines or to exclude any entire group from the possibility of being represented in the fossil state. Nevertheless, such omissions, or at least very disproportionate representations, will occur and must be allowed for. The theory also fails where a flora is only very meagerly represented, and the smaller the representation the less applicable the principle. This accounts for certain great irregularities in the diagram, which are greatest in the least adequately represented formations. Such defects will be readily rectified by the intelligent student of the diagram, and it was thought better to leave this to his judgment than to attempt to overcome the defects by an arbitrary reduction of irregularities. The numerical table will aid in making the proper allowance in each case by indicating, as the diagram cannot do, the poorly-represented horizons. Upon the whole this diagram may be regarded as trustworthy in intelligent hands and as fairly indicating all that is claimed for it.

That vegetable life should have preceded animal life is a fair deduction from all that we know of these two kingdoms of nature, and, not to speak of the much-disputed *Eozoon Canadense* of Canadian so-called Azoic rock, we at least have *Oldhamia* in the Cambrian, whose organic character is quite generally admitted. This and other facts give weight to the view that the dark carbonaceous substance found in the Laurentian has been the result of accumulated vegetable matter of marine origin, but too frail in structure to admit of preservation in any other form. Graphite, too, which is a pure form of carbon, and thus almost demonstrates vegetable origin, is found below the Silurian. But, dismissing these speculations and admitting the somewhat doubtful vegetable character of *Oldhamia*, we actually have organized plants, marine algæ, preserved in the Lower Silurian and even at its base. Such are *Bilobites rugosa*, *Chondrites antiquus*, and *Sphaerococcites Scharyanus*. The Cellular Cryptogams are thus fairly introduced at points lower than that of the appearance of any higher type of vegetation, and by the close of the Silurian fifty species had made their appearance, constituting 85 per cent of all the life of that epoch as thus far found. Not only in this case, but all through the series, the order in which these great types of vegetation are here drawn up agrees substantially with that of their appearance on the globe, as shown by actual specimens collected and determined. If the system of classification had been based exclusively upon paleontological data, there would be no force in this, but, as I have shown, it is in large measure that of botanists proper who never

argue from paleontology, and most of the points in which it differs from accepted botanical systems have been independently confirmed by structural botanists.

More remarkable still, perhaps, than the early appearance of marine algæ is that of certain well-organized vascular plants that must have inhabited the land. Among the earliest forms of terrestrial vegetation we find the ferns, those graceful forms whose green, airy fronds are still the delight of every judge of natural beauty. We have at least one well-authenticated species in the Silurian—*Eopteris Morierii* of Saporta—found by Morière a few years ago at the base of the Middle Silurian, a gilt figure of which its namer has made the frontispiece of one of his last works.[246] The fern may be almost taken to represent the primary form of the vegetative process. Its delicate spray resembles, most of all plant-forms, the exquisite frost-work which we see on our windows on a cold morning. The physicists tell us that these latter are the result of molecular activities and consist in the deposit of solidified molecules of invisible vapor. Plant-growth consists in the deposit of solidified carbon molecules upon the growing surfaces of plants. Perhaps, then, we should not wonder at the resemblance between the earliest forms of plant life and those other forms which nature creates by the action of the same principle, and which the chemist can imitate in certain modes of precipitation.

In the Devonian we have 79 species of ferns, and this type of vegetation reaches its maximum in the Carboniferous epoch, which, if we extend it to include the Subcarboniferous and the Permian, furnishes 877 species, forming nearly 45 per cent of the total flora of that epoch. There are good reasons for supposing that during this age the ferns were nearly all arborescent and really formed a large part of the Carboniferous forests. From this time forward they declined both in number and vigor until, at the present time, they are only 2 per cent of the vegetation of the globe, and in nearly all cases consist of low herbaceous plants, almost valueless except for their singular beauty.

Let us next consider the type which is here denominated the *Equisetineæ*. At the present time the natural order *Equisetaceæ* embraces all the plants of this group, and they are very few indeed and insignificant in size, but in the Carboniferous age they formed nearly 10 per cent of the vegetation, and furnished the great Calamites, which clearly show that they were no mean element in the forest growth of that period. Certain plants of this group—*Sphenophyllum primævum*, *Annularia Romingeri*—were found by Mr. Lesquereux in the Cincinnati group of the Silurian, an horizon, perhaps, lower than that of *Eopteris*, and we must therefore regard this type as of exceedingly ancient origin. The Calamites disappear entirely in Mesozoic time and the type dwindles into insignificance.

[246] Le Monde des Plantes avant l'apparition de l'homme. Paris, 1879. (See pp. 35, 166.)

The *Lycopodineæ*, now represented by the natural order *Lycopodiaceæ*, and constituting little more than one-third of 1 per cent of the living vegetation of the globe, embraced in the Carboniferous epoch the lepidodendroid group. About four hundred species of these plants have been described from the Subcarboniferous to the Permian, and during their reign they formed nearly one-fourth of the vegetation of the globe. They were the largest forest trees of their time, and sometimes attained a great size, though, of course, nothing approaching the giants of our present forests. This ancient, or archaic, type disappears entirely with the Permian, and never reappears. Its degenerate descendants continue down to the present, chiefly in the form of club mosses, of which considerable variety exists.

The two remaining groups of cryptogamic plants, the *Rhizocarpeæ* and the *Ligulatæ*, possess little paleontological importance, although the number of species, including spore-cases, that have been referred to the former of these orders has now reached seventeen, four of which are Paleozoic (Devonian and Subcarboniferous) and four Mesozoic. These, as well as most of the Miocene species, belong to the genus *Salvinia* or one nearly allied to it (*Protosalvinia* Dawson), although one *Pilularia* has been found at Œningen, and a true *Marsilia* occurs in an undescribed collection now in my hands, made by Captain Bendire in the Miocene of the John Day River region, Oregon, and which I propose to call *Marsilia Bendirei*, should there prove to be no inaccuracy in this determination.

As regards the *Ligulatæ*, they are still less frequent in the fossil state, and are thus far represented only by the two very dissimilar genera, Selaginella and Isoetes. Unless, as has been affirmed, the former of these genera has its representatives in the Carboniferous, the group is not found lower than the Cenomanian of Atane, Greenland, where Heer has detected his *Selaginella arctica*. Mr. Lesquereux has described three species of this genus in the Laramie group, and the same author has found a true *Isoetes* in our Green River Eocene, at Florissant, Colorado. Two more species of Isoetes from the Miocene of Europe exhaust the enumeration, making in all only seven species of Ligulatæ.

We have thus rapidly glanced at the relative development of each of the cryptogamous types of vegetation, and will next consider that of the phanerogamous types. As already shown, the Gymnosperms stand lowest, and have probably, in some still undiscovered way, descended from the Cryptogams. Of these we place the Cycadaceæ lowest on account of their endogenous growth, circinate estivation, and other characteristics which seem to ally them to the ferns. Still, as the lines are now drawn by the best authorities, the Cycadaceæ cannot be traced below the Carboniferous, while the archaic progenitors of the Coniferæ extend far down into the Silurian. If we refer the *Medullosæ* to the ferns, as Renault and Grand' Eury would have us do, only three cycadaceous plants occur in the Carboniferous; but one of these is a true

Pterophyllum from the coal measures of China, and there is probably a second from Europe. Fourteen species occur in the Permian, including the typical genera *Dioonites* and *Clathraria*. It is not, however, until the Keuper is reached that this type of vegetation assumes a leading part, and throughout the Jurassic it continues to be the most abundant form of plant life. In the Lias it forms 43 per cent of the flora of that formation, though this may be accidentally exaggerated. It was 28 per cent of the Oolitic flora and more than 35 per cent of that of the Wealden. From this point, however, its decline was rapid and uninterrupted until in the living flora only 75 species of cycadaceous plants are known to botanists. Of these North America can claim but a single one, the sago-palm (*Zamia angustifolia*) of our extreme Southeastern States.

Passing to the Coniferæ, we find the *Cordaites Robbii* of Dawson from the Devonian of Canada recurring in the Upper Silurian of Hérault. This genus was formerly supposed to be the prototype of the Cycadaceæ, but, as already remarked, this opinion is now abandoned by the best authorities, and the genus referred to the Coniferæ. The evidence upon which this change rests cannot be presented here, but it is proper to say that the savants who have marshaled it have done so in such a manner as to render their conclusion akin to irresistible. But its adoption has carried with it a train of consequences which cannot be escaped. Not *Cordaites* alone, or with its spore-bearing parts (*Cordaianthus*) and its fruit (*Cordaicarpus*), but *Nœggerathia*, *Trigonocarpus*, *Cardiocarpus*, *Rhabdocarpus*, *Sternbergia*, *Artisia*, etc., must all follow in its wake and be gathered, one and all, into the great family of the Coniferæ. It is thus, as shown by our table and diagram, that this type assumes such a commanding position far back in Paleozoic time, forming about one-fourth of the vegetation of the Permo-carboniferous epoch. Doubtless this effect is exaggerated by duplications caused by giving different names to separate parts of the same plant, but this occurs throughout the series only to a less obvious degree.

The true Coniferæ, which have some representatives in the Paleozoic, replace the *Cordaiteæ* entirely in the lower Trias and thereafter vie with the Cycadaceæ for supremacy, which they do not fairly attain until the lower Cretaceous is reached. Being of a higher type of structure than the latter by reason of their exogenous mode of growth and other peculiarities, they refuse to succumb in competition with the now rising Angiosperms and continue to hold their own through much of the Tertiary. At the present time the number of known species (300) would denote a great decline, but this is in large part made up by the wonderful predominance and territorial expansion of these persistent forms. Although from the point of view of the number of species alone, the present Coniferæ would form but one-fourth of 1 per cent of the vegetation of the globe, we in fact find vast tracts of country covered with pine, fir, and spruce forests, excluding almost completely

all other types. But that the pine family is now waning there can be no doubt. Important forms have wholly disappeared, and others that once were abundant have now nearly vanished from the earth. Of this last truth an example of unusual interest is furnished by the genus *Sequoia*. Of the score or more of species that made up so large a part of American Tertiary forests our well-known "big tree" of the Sierras (*S. gigantea*) and our California red-wood (*S. sempervirens*) now stand alone and continue the combat against fate—the closing struggle of a dying race.

Of the *Gnetaceæ* I need not here speak, as its paleontological record is almost *nil*, and its importance depends upon circumstances wholly disconnected from its prevalence as a type of vegetation.

We come now to the Angiosperms. A great step forward had been taken, and in her solicitude for her offspring Nature had, as it were, built a house over the hitherto unprotected germs of plant life. The closed ovary marks an era in the march of vegetal development.

The earliest form in which the Angiosperms appeared was that of the Monocotyledon. Issuing from the seed and from the ground as a single spear or blade, the plants of this type grow up chiefly by an internal circulation which can only deposit nutrition at the apex (endogenous growth). As the lowest type of Angiosperms we find them, according to our scheme of classification, occupying also the earliest position in the stratified deposits of the earth's crust.

The existence of Monocotyledons in the Carboniferous and Permian was long disputed, although Corda, after the most exhaustive study of their structure, was obliged to refer two species of endogenous wood to that subclass. This determination has been thus far sustained, and to these have been added *Palæospathe Sternbergii*, Unger, in the Carboniferous, and two other species in the Permian. The very problematical *Spirangium* has generally been regarded as the fruit of some Xyris-like Monocotyledon, and this view has been quite recently defended by Nathorst. Its occurrence in the Carboniferous is now also abundantly established by its discovery at Wettin, at Saint Etienne, and at Pittston, Pennsylvania. Certain lily-like forms, called *Yuccites*, are found in the lower Trias, and through the remaining Mesozoic these forms increase slowly and are reinforced by screw-pines and a few sedge-like plants. The monocotyledonous vegetation, however, does not receive any marked character until the advent of the great palm family, which dates from the Middle Cretaceous. From this time, notwithstanding the rivalry of the now dominant Dicotyledons, this type progressed, reaching its relative maximum in the Eocene. Overslaughed by the higher growths, it thenceforward declined, but still numbers some 20,000 species and forms over one-eighth of the total flora of the present epoch.

The step from the Monocotyledon to the Dicotyledon is very great, and it seems to have required a vast period of time to accomplish it.

Not only must a new form of growth from the seed and from the ground be developed, and a sort of bilateral symmetry be introduced, but in addition to this, and, as I believe, in great part due to it, the exogenous mode of circulation and tissue growth must supplant the endogenous one, whereby the stem may increase in thickness as well as in length. These great mechanical problems were worked out during Mesozoic time and in the Middle Cretaceous, represented in this country by the Dakota group, and in Europe by the Cenomanian epoch, the great type of plant life appeared which was destined to dominate the world and sink all other forms into insignificance. But the most astonishing fact is that this young giant was born, as it were, full grown. In this lowest horizon at which any Dicotyledons appear[247] we have already obtained more than three hundred species belonging to all three of the great divisions of the subclass, and exhibiting ample, luxuriant foliage. They embrace many of our most familiar forms, the poplar, the birch, the beech, the sycamore, and the oak. Here appears the fig tree, the true laurel, the sassafras, the persimmon, the maple, the walnut, the magnolia, and even the apple and the plum. We must conclude, then, that the Dicotyledons had a much earlier origin than is shown by our defective record, and that they had been long developing through the Mesozoic ages.

If now we follow the advancing wave of plant life from this point upward we shall see that from the new vantage-ground furnished by the closed ovary, the perfect flower, and the exogenous trunk, its march was rapid and steady until we reach the Miocene Tertiary, the culminating point in the paleontological series. Here the species actually found are numbered by thousands, and the higher types greatly predominate over the lower ones. But from this point the record begins to fail, and can no longer be trusted. Very little is found in the Pliocene, and still less in the Quaternary; but this cannot indicate an actual decline in these types of vegetation. It must be due to the approach of a state of things which rendered the preservation of vegetable remains difficult, a condition, as already remarked, which is especially characteristic of the present state of the globe. The march of the Dicotyledons was uninterrupted, and still continues. The figures given in the numerical table represent, in round numbers, the estimates of Messrs. Bentham and Hooker, as given in their "Genera Plantarum," and may, therefore, be taken as the most reliable that can be obtained. The three divisions of the Dicotyledons combined amount to 87,000 species, and constitute nearly 60 per cent. of the flora of the globe.

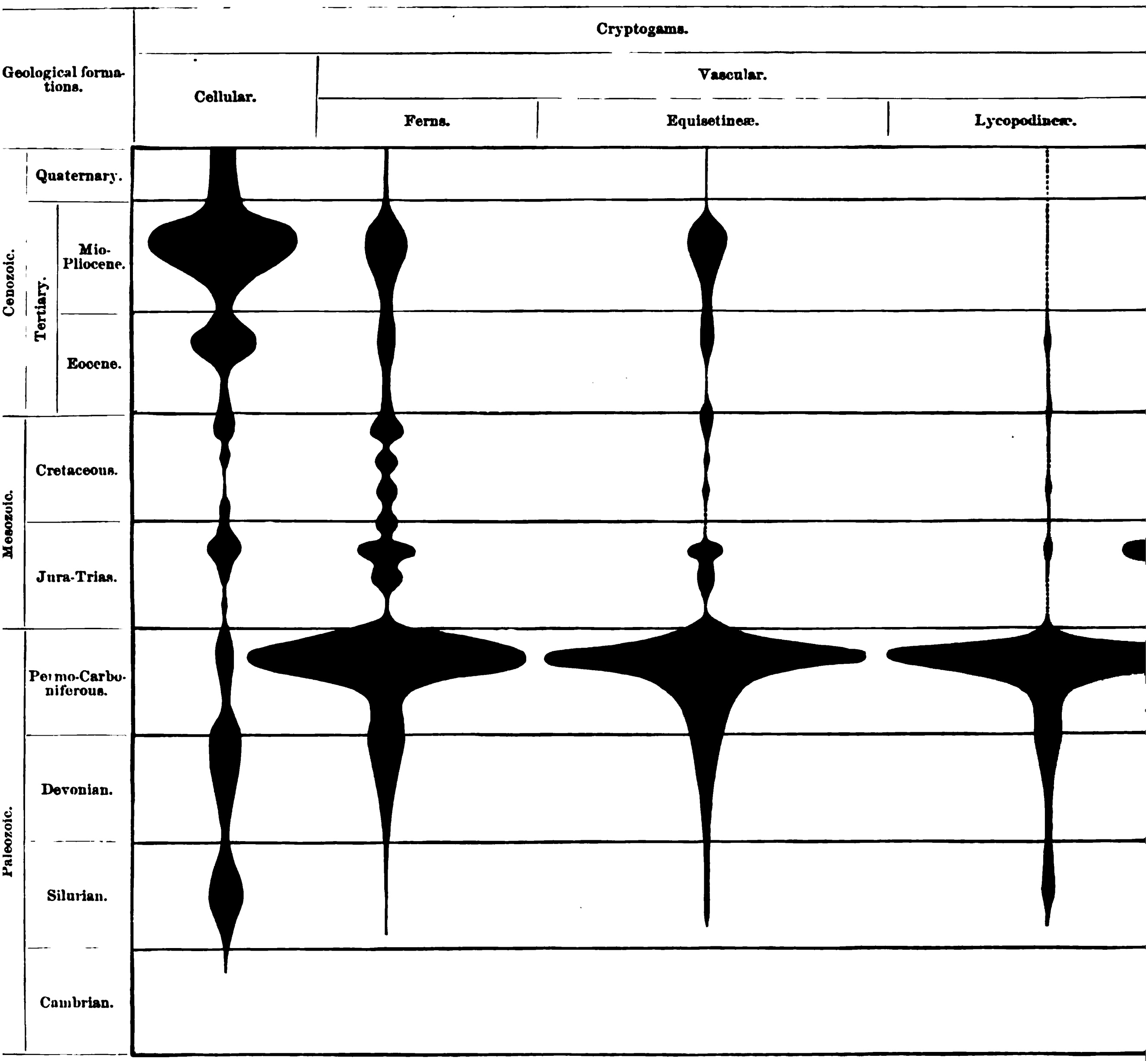
With regard to the three divisions of the Dicotyledons, although they are all represented in the lowest formation at which any considerable number are found, still the Apetalæ constitute a larger proportion of the Dicotyledons in the Cenomanian (45 per cent) than in the Miocene (37

[247] If we accept the solitary *Populus primæva*, Heer, from the Urgonian beds of Kome, Greenland.

per cent), and very much larger in the Tertiary than in the living flora (14 per cent), while the Gamopetalæ, which constitute only 5 per cent in the Cretaceous, reach 15 per cent in the Miocene, and 46 per cent in the living flora, here exceeding the Polypetalæ. From these facts it is evident that the order of development is such as I have here given it, and that the type of the future is to be not the Polypetalæ but the Gamopetalæ. These conclusions are independently corroborated by a large mass of evidence of other kinds, but space forbids me to adduce it in detail. I may simply say, however, that just as the closed ovary of the Angiosperm in general furnished a condition for the development of that class at the expense of the unprotected Gymnosperm, so the two floral envelopes of the Polypetalæ and Gamopetalæ enabled those divisions to outstrip the Apetalæ with its single floral envelope; and since this advantage is proportional to the degree of protection secured, the Gamopetalæ, with their tubular corollas are manifestly better adapted to survive in this respect than the Polypetalæ. This is the chief argument, and, putting it with that from paleontology, it seems sufficiently conclusive without detailed support.

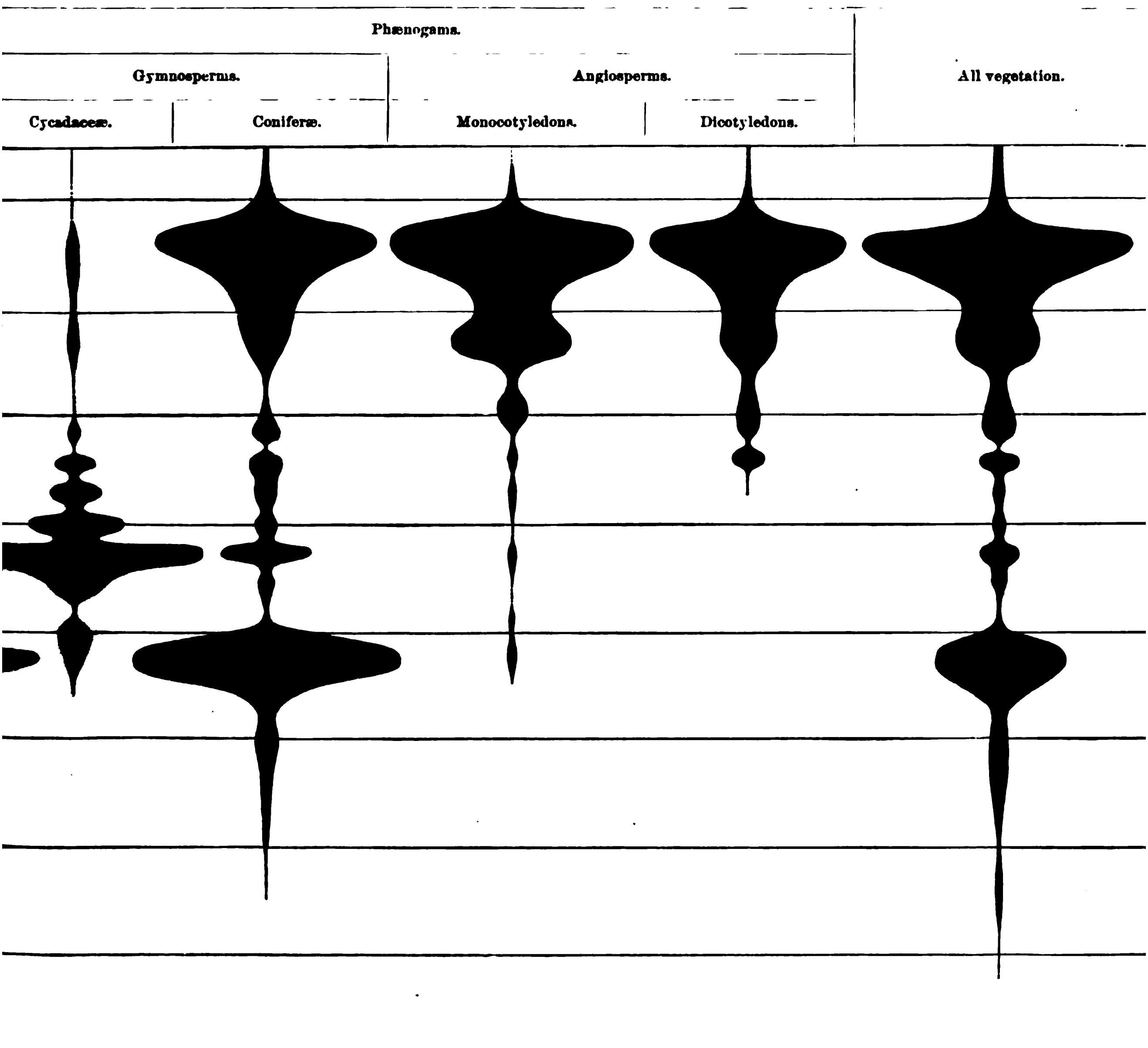
Discussion of Diagram No. II.—In this diagram the time equivalents are the same as in the last, but only the more important types are represented. The Rhizocarpeæ, Ligulatæ, and Gnetaceæ are omitted, and the Dicotyledons as a whole are shown, disregarding their subdivision into Apetalæ, Polypetalæ, and Gamopetalæ. A figure is added representing the total of all the formations, and this is probably the most important of them all, as least affected by the gaps and fluctuations in the record. No account could, of course, be taken of the living flora, as is done in Diagram No. I, for while between the fossil and the living floras there is a similarity in the proportion that the types in each bear to the sums of such floras, no such analogy holds between the number of species actually known in any fossil flora and the number in the living flora. This, at least, is true of the total floras and of all the types except, perhaps, the Cycadaceæ and the Coniferæ. But even here the comparison would fail to express the rapid decline which these forms have evidently undergone, at least so far as the number of their species, which represents their diversity, is concerned.

While the diagram is of little service as a means of representing the true development of each type of vegetation or of the general flora of past ages, it has considerable value as an exponent of the true character of the phyto-geologic record. It shows more clearly and more strikingly than any words or figures could do the great differences that characterize the different periods of geologic time in their susceptibility to deposit, preserve, and afterwards expose to scientific investigation the vegetable forms that constituted the floras of those periods. While this is well shown for the several dominant types it is especially obvious in the figure illustrating the entire flora. Here are brought prominently into view, first, the age of island vegetation in the Carbon-



DIAG

SHOWING THE OBSERVED ORIGIN AND DEVELOPMENT OF



t No. 2.

E PRINCIPAL TYPES OF VEGETATION IN GEOLOGIC TIME.

iferous; next, the second and still greater age of extensive marsh, vast low plains cut by shallow estuaries or partially or wholly cut off from the sea and forming brackish or fresh water deposits, which culminated in the Miocene; then, the two intermediate periods of only less favorable conditions occurring in the Brown Jura and the Cenomanian, respectively; and, finally, the long intermediate ages of less favorable or wholly unfavorable conditions and the abrupt termination of the entire period of plant deposition which accompanied the age of mountain building towards the close of the Tertiary. The almost complete absence of vegetable remains in the Trias, the lower Cretaceous, and the Turonian of both continents points to the probable general subsidence of land areas at those epochs, at least for such portions of the earth's surface as have been explored by paleontologists. But the great relative abundance of such life in the middle and again in the extreme upper Cretaceous shows that those must have been great land areas at all times—areas which are now either under the sea or belong to some of the still scientifically "unexplored regions" of the globe. The proof of this is made conclusive by the fact that new and higher types come forth abruptly in these floras which must have required ages of most favorable conditions for their prior development.

Discussion of Diagram No. III.—This diagram is simply the application of the rational scientific method to the incomplete facts afforded by the present infantile state of the science of fossil plants. It does not pretend to give the exact history of plant development, but only to constitute a certain advance in this direction beyond what the fragmentary data out of which it is constructed can alone furnish. For example, it is certain that the earliest record discovered by man of the existence of any type of vegetation cannot mark the absolute origin of that type, and it is therefore necessary in every case to project the type downward to an unknown distance. If the real facts could be indicated we should see during these unrecorded periods the actual transformations which must also be assumed to have taken place in each case before the fully-developed type could appear. This we are unable to represent, and must merely indicate the early history of each type by its downward projection to an assumed point of origin. Neither can it be supposed that the great fluctuations shown in the diagram last considered are due altogether or chiefly to fluctuations in the degree of vigor, territorial expansion, or local prominence of the given form of vegetable life. They are the results of varying geological conditions or of human good fortune, while the modifications in the forms themselves take place slowly and at uniform rates either in the ascending or the descending scale. Recognizing this law of uniformity, no fluctuations in any homogeneous type have been admitted, but simply a more or less regular development in each from its assumed point of origin to its supposed period of maximum predominance, followed by an equally uniform decline to the present epoch when its condition relative to past

epochs is also indicated. The only exception to this rule has been made in the case of the Cellular Cryptogams, whose heterogeneous character has doubtless caused it to undergo considerable fluctuation. One such is assumed in the Carboniferous, in which, though one of the great periods of vegetable deposition, the actual number of Cellular Cryptogams falls below that of either preceding or subsequent periods. This seems to argue that there was a reduced representation of this form of plant life in that age, and this is shown in the figure presented for that type.

The three facts which this diagram aims chiefly to bring out, not shown in either of the preceding diagrams, are, first, the true origin, or geological age of first appearance of each type of vegetation; second, the period of its maximum development; and, third, the rank it occupies in the living flora relative to its maximum. These are all delicate points to fix in a manner that will satisfy all the conditions of the problem. The evidence from all sides has to be cautiously weighed, care taken not to give undue weight to any nor to undervalue any. These are not questions that can be hastily settled. They require to be pondered long and well. It is by no means claimed that substantial truth has been reached in every case. No two persons, however competent, would probably exactly agree upon all the points, and I am sure that at different times with increasing evidence I have modified my own conclusions. But this is far from confessing that the attempt is valueless, and it is certain that great value should be attached to the enlarged conceptions of vegetal development that flow from such a study.

Descent of plants.—But we need not stop here. The great law of development does not allow us to contemplate these types as independent of one another. Each class of plants must be regarded as the descendants of some ancestral form more or less different from it. The multiple origin of existing forms, whether of plants or animals, is repugnant to modern scientific thought. It is the discovery of facts that has rendered it so. The multiple and varied of the present must be regarded as due to divergences in the past. The forms we have have come down to us along divergent lines from common ancestral forms. These are the *lines of descent*, and plants have their lines of descent as well as animals or human families. Of this we are practically certain, but just what those lines are and where they diverged—these are the great problems of phytogeny.

The lines of descent in the animal kingdom have been laid down by various eminent zoölogists with considerable confidence and unanimity. In plant life they have scarcely ever been attempted. The problem is loaded with extraordinary complications and cannot be satisfactorily attacked until we shall possess far more knowledge than we possess at present.

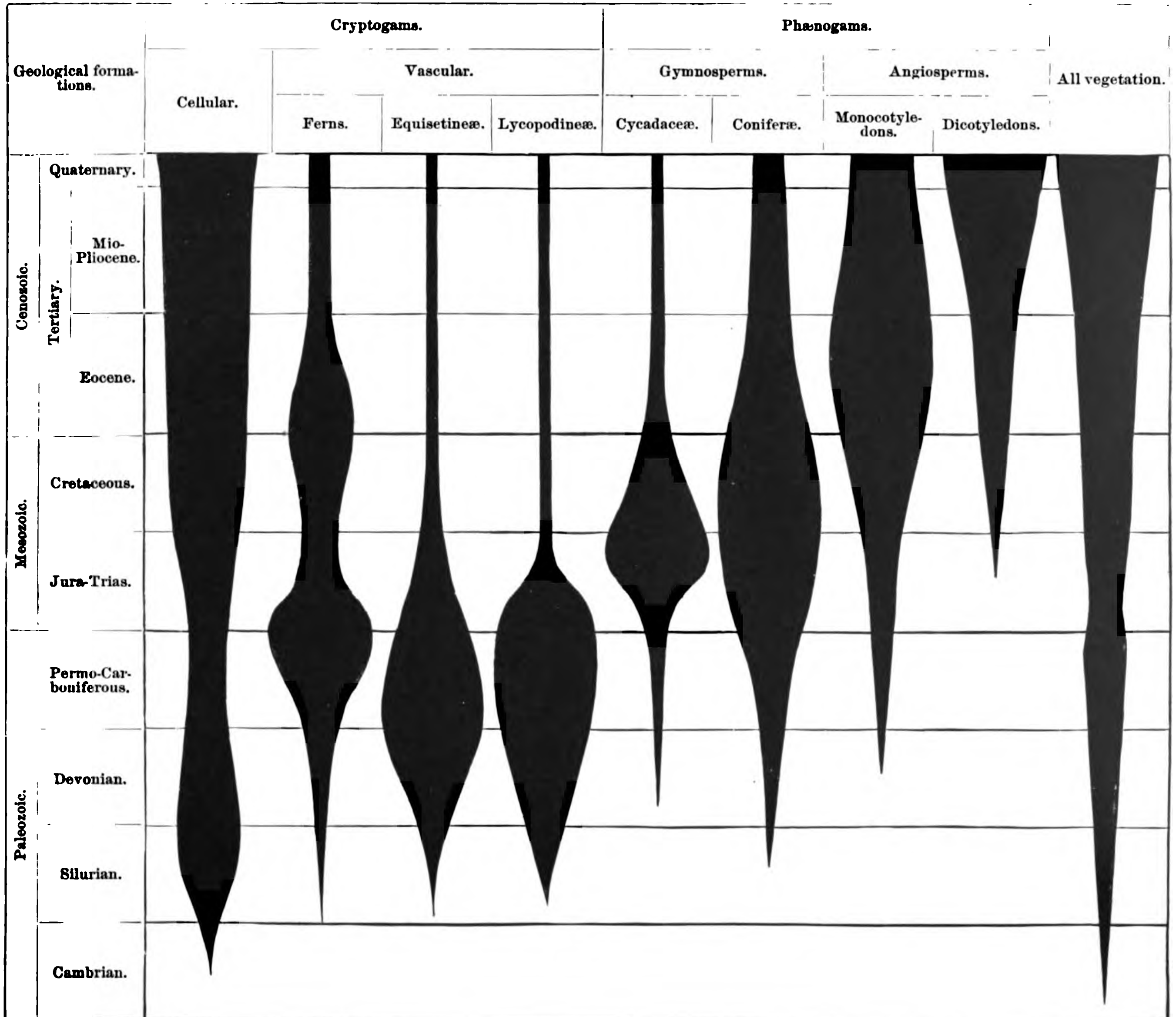


DIAGRAM NO. 3.
SHOWING THE ASSUMED ORIGIN AND DEVELOPMENT OF THE PRINCIPAL TYPES OF VEGETATION IN GEOLOGIC TIME.

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